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**DIVISION OF MINERAL RESOURCES**  
**JASPER L. STUCKEY, STATE GEOLOGIST**

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**BULLETIN NUMBER 61**

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# **SILLIMANITE DEPOSITS**

## **in North Carolina**

**BY**  
**LEWIS J. HASH**  
**AND**  
**EARL C. VAN HORN**

**EDITED BY**  
**KEFTON H. TEAGUE**

●

**PREPARED IN COOPERATION WITH THE TENNESSEE VALLEY AUTHORITY**

●

**RALEIGH**  
**1951**







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## LETTER OF TRANSMITTAL

Raleigh, North Carolina

April 19, 1951

*To His Excellency, HONORABLE W. KERR SCOTT*  
*Governor of North Carolina*

SIR:

I have the honor to submit herewith manuscript for publication as Bulletin 61, "Sillimanite Deposits of North Carolina." This Bulletin is another in a series being made possible by the cooperation of the Tennessee Valley Authority.

Considerable interest has been developed in sillimanite and other aluminum silicate minerals in recent years. It is believed that this report will be of considerable value to those interested in aluminum silicate minerals.

Respectfully submitted,

GEORGE R. ROSS,  
*Director.*



# CONTENTS

	<i>Page</i>
INTRODUCTION .....	1
Purpose and Scope .....	1
History .....	1
Field Work and Acknowledgments .....	1
PROPERTIES OF SILLIMANITE .....	2
USES OF SILLIMANITE .....	2
ORIGIN .....	2
SILLIMANITE IN THE CLIFFSIDE-ELKIN BELT .....	3
Physical Geography .....	3
Geology .....	4
Description of Deposits .....	6
Polkville Deposit .....	6
Wards Creek Deposit .....	6
Casar Deposit .....	6
Smith Cliff Deposit .....	8
Saw Mills Deposit .....	10
Cages Mountain Deposit .....	10
Dudley Shoals No. I Deposit .....	12
Dudley Shoals No. II Deposit .....	14
Dudley Shoals No. III Deposit .....	16
Ellendale School Area .....	16
Fox's Orchard Deposit .....	16
Wilkesboro-Taylorsville Area .....	17
SILLIMANITE IN THE WARNE-SYLVA BELT .....	17
Physical Geography .....	17
Geology .....	18
Descriptions of Deposits .....	20
Brasstown Church Cherry Mountain Deposit .....	20
Hyatt Mill Creek Deposits .....	23
Downing Creek Deposits .....	23
Sap Sucker-Cold Branch Deposits .....	25
Tusquitee Gap-Jarrett Creek Deposits .....	25
Burningtown Deposits .....	26
Saldeer Deposits .....	26
Oak Grove Deposits .....	28



## CONTENTS—CONTINUED

	<i>Page</i>
Etna-Bradley Creek Deposits .....	28
Rickman Creek Deposits .....	28
Matlock Creek Deposit .....	30
Leatherman Deposits .....	30
Cowee Church Deposits .....	30
Greens Creek School Deposits .....	30
Brook Branch-Sutton Branch Deposits .....	32
Riverview Church Deposits .....	32
Sylva Deposits .....	32
OTHER SILLIMANITE DEPOSITS .....	35
Grassy-Ridge-Big Ridge Deposits .....	35
South Hominy Deposit .....	35
Asheville-Mount Mitchell Deposits .....	36
LABORATORY RESULTS .....	36
Method Employed for Sample Analysis .....	36
Analysis and Location of Samples from the Cliffside- Elkin Sillimanite Belt .....	37
Description of Heavy Minerals in Sillimanite Ore From Cliffside-Elkin Belt .....	38
Analysis and Location of Samples From the Warne-Sylva Sillimanite Belt .....	41
Description of Heavy Minerals in Sillimanite Ore From Warne-Sylva Belt .....	42
Beneficiation .....	45
Introduction .....	45
Procedure .....	45
Cages Mountain Deposit .....	45
Fox's Orchard Deposit .....	46
Smith-Cliff Deposit .....	46
Dudley Shoals Deposits .....	47
Grassy Ridge Deposit .....	48
Conclusion .....	49
PROSPECTING, MINING AND RESERVES .....	49
POSSIBILITIES FOR DEVELOPMENT .....	50
REFERENCES .....	52



## PLATES

PLATE	<i>Page</i>
1. Occurrence of Sillimanite in Cliffside-Elkin Belt of North Carolina.....	7
2. Smith Cliff Sillimanite Deposit, Burke County, North Carolina.....	9
3. Valdese-Dudley Shoals Sillimanite Area, Burke, Caldwell, Alexander Counties, North Carolina.....	11
4. Cages Mountain Sillimanite Deposit, Caldwell County, North Carolina .....	13
5. Dudley Shoals No. I Sillimanite Deposit, Caldwell County, North Carolina .....	15
6. Occurrences of Sillimanite in the Warne-Sylva Belt of North Carolina .....	19
7. Hayesville Area: Brasstown Church-Cherry Mountain Sillimanite Deposits .....	21
8. Hayesville Area: Hyatt Mill Creek Sillimanite Deposits.....	22
9. Hayesville Area: Downing Creek Sillimanite Deposits.....	24
10. Etna-Cowee Area: Saldeer Sillimanite Deposits.....	27
11. Etna-Cowee Area: Oak Grove-Matlock Creek Sillimanite Deposits .....	29
12. Etna-Cowee Area: Leatherman Sillimanite Deposits.....	31
13. Greens Creek Area Sillimanite Deposits.....	33
14. Sylva Area Sillimanite Deposits.....	34



# INTRODUCTION

## PURPOSE AND SCOPE

This report describes the principal sillimanite deposits in North Carolina. In the first comprehensive report on a new mineral it is desirable to give a complete description of the geology of the mineral, but time allotted to the study did not permit detailed geological studies; therefore, this phase of the report has been kept to a minimum. An attempt has been made to assemble the data in such form that they would be of use to those who are interested in prospecting, mining, and using sillimanite.

The reconnaissance field work has shown that sillimanite occurs in most all counties west of the central Piedmont area of the State. The major sillimanite deposits and those offering the best production possibilities occur in two belts, one located in the upper Piedmont, designated "the Cliffside-Elkin belt", and the other located west of the Blue Ridge designated "the Warne-Sylva belt." The authors are aware of sillimanite occurrences outside of these two principal belts, but most of these other known occurrences are small and appear to be of little economic importance. The two principal belts are so extensive that it was not feasible to obtain all the desired data.

Since the deposits are spread over large areas, one of the problems confronting those interested in the sillimanite has been that of determining which deposits are best suited for mining and concentration. It is hoped that the data presented in this report will serve to delimit the deposits so that the more promising ones can be more readily selected.

Laboratory data, regarding the percentage of sillimanite in and methods of beneficiation of the various ores, have been included in this report to show the possible methods of treatment and type of concentrates that can be produced from North Carolina deposits.

## HISTORY

Prior to 1900 sillimanite grains were identified in concentrates from placer operations for monazite<sup>7\*</sup> (1915) and corundum<sup>8</sup> (1905), however, this early published literature made no mention of the primary source of the sillimanite. During the early part of 1944 Charles E. Hunter of the Tennessee Valley Authority noted extensive sillimanite schist occurrences in the vicinity of Valdese, Burke County, North Carolina. In the summer of 1945 Hunter and White<sup>3</sup> made a reconnaissance survey and found that the sillimanite deposits in the upper Piedmont area extended from the South Carolina line northeastwardly, to the Yadkin River in the vicinity of North Wilkesboro and Elkin.

Probably the first reference to sillimanite in the "Warne-Sylva belt" was that of Prindle<sup>9</sup> who mentioned occurrences in the vicinity of Hayesville, Clay County. In 1945 Furcron and Teague<sup>2</sup> described sillimanite in the same vicinity, referring to unpublished field studies of J. L. Calver and W. T. McDaniel, Jr., Geologists, TVA, who made reconnaissance studies of Clay County sillimanite deposits in 1944.

To date, there has been no production of sillimanite from the North Carolina deposits, however, since the discovery there has been continued interest in these occurrences by various individuals and mining companies.

## FIELD WORK AND ACKNOWLEDGMENTS

The field work for this report was conducted as a joint project between the North Carolina Division of Mineral Resources and the Regional Minerals Section of the Tennessee Valley Authority. General supervision of the studies was under Jasper L. Stuckey, State Geologist of North Carolina, and the late H. S. Rankin, Senior Mining Engineer of TVA. The work was under the direct supervision of Charles E. Hunter and details of the survey were conducted by Earl C. Van Horn and Lewis J. Hash, Geologists of the TVA. Field assistants provided by the North Carolina Division of Mineral Resources included P. A. Hager, J. H. Recknagel, W. C. Cole, and J. H. Davis.

The percentage of sillimanite and petrographic characteristics of the field samples were determined by Euan K. Green, Student Assistant of the North Carolina Division of Mineral Resources. The field survey

\*References at end of report.



was started in June 1949 and completed in September of the same year. The data regarding beneficiation of the sillimanite ore were obtained from laboratory studies by W. T. McDaniel, Jr. and Mason K. Banks, Mining Engineers of TVA, and W. H. Powell, Jr., Ore Dressing Engineer of the North Carolina State College Minerals Research Laboratory. Chemical analyses were prepared by Phillip N. Sales, Chemist, North Carolina State College Minerals Research Laboratory. Maps included in this report were prepared by the Maps and Surveys Branch of TVA.

### PROPERTIES OF SILLIMANITE

Sillimanite, like kyanite and andalusite, has the theoretical chemical composition of  $\text{Al}_2\text{O}_3\cdot\text{SiO}_2$ . It has a vitreous-silky to a subadamantine luster, specific gravity of 3.2-3.3 and is gray to bluish gray in color. The hardness varies between 6 and 7 in Mohs' scale. Under the binocular microscope the crystals are transparent. The mineral may occur as needles (fibrolite), composed of fibrous sometimes radiating hair-like crystals, in schist or as coarse bundles of crystals (nodules) disseminated in schist.

When heated above  $1650^\circ\text{C}$ . sillimanite expands about 6.5 percent and is converted into a stable mixture consisting of mullite ( $3\text{Al}_2\text{O}_3\cdot\text{SiO}_2$ ) and vitreous silica, with a specific gravity of about 3.15.

In the Warne-Sylva belt part of the sillimanite apparently has been formed from the alteration of kyanite to sillimanite, however, the identity of these two minerals can be separated readily in the field by a simple test of hardness. Also most sillimanite shows sericitization, however, this type of alteration can too be readily detected by a hardness test.

### USES OF SILLIMANITE

Since sillimanite has never been produced on a commercial scale there are no established uses for the mineral; however, as its various properties including physical, chemical, and thermal are known, certain potential uses can be listed.

Sillimanite shows no apparent change when heated below  $1600^\circ\text{C}$ ., thus it can be incorporated into refractory bodies for service below that temperature. For service in excess of  $1650^\circ\text{C}$ . sillimanite is converted into mullite. Some of the potential uses for sillimanite include porcelain for spark plugs, high-alumina refractory brick, crucibles, saggars of all types, high temperature cements, linings for indirect-arc and heat-treating furnaces, pyrometer tubes, and glass-tank blocks.

Research directed toward the use of sillimanite in porcelain has been conducted at Clemson College, South Carolina.<sup>11, 12</sup> Results from these investigations indicate that when sillimanite is substituted for flint in porcelain bodies, strength is increased greatly, resistance to shock, etc. is improved, thus opening a field for finely-ground sillimanite in the ceramic porcelain industries.

### ORIGIN

Considerable difference of opinion exists as to the importance of regional and thermal metamorphism, hydrothermal action, composition of igneous intrusions, composition of original sediments, and character of assimilation in the formation of sillimanite. Insufficient data are available upon the sillimanite-bearing rocks and adjacent surrounding rocks of the North Carolina sillimanite deposits to permit a positive statement as to their origin.

Furcron and Teague<sup>2</sup> in discussing the sillimanite deposits in Hart, Elbert, and Madison Counties, Georgia, state that "without doubt the original sediment has been altered by large scale folding and regional metamorphism, but these rocks, representing the folded roots of the old sedimentary formations, are all altered and more coarsely crystallized than are the rocks to the west which have also suffered the same regional effects. The recrystallization of the muscovite, biotite and sillimanite is believed to be due to the intimate relation of the rock here to the intrusive granites, pegmatitic granites, and pegmatites." In studying deposits in the Davy Mountain area of Georgia which are the southwestern continuation of the "Warne-Sylva belt" of this report, these same workers state that "the sillimanite occurs in zones of muscovite-graphite schist which were probably highly aluminous, representing an old meta-sedimentary facies of the pre-Cambrian gneiss . . . . Some specimens from Davy Mountain and other localities still retain the structure and



outward appearance of kyanite, thus it appears that locally, at least, kyanite produced by hydrothermal alteration of the schist was converted to sillimanite through the action of later, hotter pegmatite solutions." Smith<sup>13</sup> who has studied the sillimanite deposits in South Carolina states "Sillimanite has resulted from contact metamorphism of a schist by granite intrusions . . . . There is no evidence that any new constituents have been added to the schist by igneous metamorphism. The sillimanite has apparently been developed by the agents of heat and aqueous solutions."

Sillimanite in North Carolina is not confined entirely to the highly argillaceous rocks (now schist), but occurs also in quartzite. Chemical analyses of sillimanite rock from neither of the two belts are available. Criteria relating to the origin of the sillimanite are based, therefore, on physical distribution of the sillimanite and its associated minerals. Structural control in the localization of sillimanite is quite evident both in the Warne-Sylva belt and in the Cliffside-Elkin belt. In addition to structural features, the deposits exhibit uniformity in that all are associated with more or less intense pegmatization.

As to mineral associations in the sillimanite deposits, muscovite, sericite, biotite, and quartz are present without exception. Kyanite, garnet, staurolite, zircon, rutile, ilmenite, barite, and graphite are evident in most of the sillimanite-bearing rock and may be present in all. Tourmaline, sphene, clinozoisite, and chromite have been identified from some of the deposits.

Kyanite and garnet are sometimes abundant in both of the two principal sillimanite belts where sillimanite is absent or present only in small amounts. Locally, sillimanite pseudomorphs kyanite and probably replaces and is replaced by muscovite and quartz. These and other criteria are related to conceptions of zone metamorphism and metamorphic facies which have been reviewed recently by such writers as Moore,<sup>6</sup> Ramberg,<sup>10</sup> Turner,<sup>15</sup> and Weiss.<sup>16</sup> In the North Carolina deposits available evidence does not indicate that the sillimanite was formed in zones of great depth. The high degree of metamorphism is more closely related to intense igneous activity.

It is believed that the ancestral rocks, containing most of the materials necessary to form the present mineral assemblages, were thoroughly foliated and sheared. Following shearing or during its last stages pegmatites were introduced into the fractured and broken rock. The excess of alumina necessary for the formation of sillimanite was derived presumably from the schist and concentrated by the pegmatites under pressure. The rock evidently did not contain sufficient potash, soda, or lime to use all the available alumina to form feldspar or muscovite.

After the formation of sillimanite later solutions were active in altering the sillimanite. Some of the deposits contain much sericite which has pseudomorphed sillimanite.

## SILLIMANITE IN THE CLIFFSIDE-ELKIN BELT

The geology and mineralogy of the two principal sillimanite belts are somewhat similar, but vary greatly in detail. Complete descriptions of each belt are contained in separate chapters, except for the descriptions of laboratory tests. Direct supervision for the studies of the Cliffside-Elkin belt was by Lewis J. Hash, who prepared this chapter.

### PHYSICAL GEOGRAPHY

The zone of sillimanite-bearing rock designated as the "Cliffside-Elkin belt" occurs in the Upper Piedmont of North Carolina, and extends in a northeasterly direction from the South Carolina line to near Elkin, North Carolina. The belt is very irregular, being discontinuous over a width of approximately 12 miles near the South Carolina line, varying from three to five miles wide in Caldwell County, and breaking up into long narrow bands in Alexander County. The zone traverses parts of Rutherford, Cleveland, Burke, Caldwell, Alexander and Wilkes counties and is found in small areas of Lincoln, Catawba and Iredell counties.

This region has a rather dense population with the major portion of the population engaged in textile manufacture and agriculture. Larger towns located within or adjacent to the belt include Shelby, Forest City, Morganton, Valdese, North Wilkesboro, Granite Falls, and Taylorsville.

Transportation facilities in this region are adequate. Numerous state and federal highways traverse the belt in an east-west direction and several highways and improved secondary roads parallel and cross the



belt in a north-south direction, this providing adequate roads for truck transportation. The belt is also traversed in its southern portion by the Clinchfield and Ohio Railroad and the Southern Railroad, the middle portion by the Southern Railroad, and the northern portion by a branch of the Southern Railroad.

Most of the deposits are within one mile of adequate water for plant operations. Major streams from south to north include the Broad, Catawba and Yadkin rivers, all of which traverse the belt in a more or less east-west direction. Large tributary streams flow within and parallel to the belt.

Climatic conditions are favorable for "year-round" mining with minimum temperatures seldom less than 0° F. and maximum temperatures seldom exceeding 100° F. The mean annual temperature is approximately 65° F. Rainfall is distributed rather uniformly throughout the year, precipitation ranging between 50 and 60 inches per annum.

The prevailing topography in this region is typical of the Upper Piedmont, consisting of rolling hills and valleys. Two small mountain ranges traverse the belt, thus locally breaking the areal topography. South of Morganton the South Mountains, reaching a maximum elevation of approximately 2,900 feet, cross the sillimanite zone in an east-west direction. Northeast of Morganton and east of Lenoir the Brushy Mountains, rising to a maximum elevation of approximately 2,500 feet, occur along the northwestern portion of the belt. In general no association is apparent between rock types and topography except on a local scale. Many places were found where sillimanite schist and granite gneiss traversed the mountains without either type of rock causing noticeable topographic features. However in some areas of major concentration of sillimanite, the sillimanite-bearing rocks have influenced local topographic expression. An outstanding example of this condition is Cages Mountain, north of Rutherford College, where a conspicuous ridge is underlain by sillimanite-bearing rock.

## GEOLOGY

Natural exposures of sillimanite rock in the area are rare and are confined primarily to steep bluffs and banks of streams. Where excavations have been made for highway construction, road bank exposures of weathered material can be found. The scarcity of outcrops is an obstacle to detailed mapping; however, a considerable quantity of float material ranging in size from small nodules up to fragments one foot across, usually occurs in areas of sillimanite-bearing rocks. At a number of deposits the only method of sampling was to obtain float material. Prospecting will be required in most deposits in order to study the structure, size, composition, etc.

The better sillimanite deposits occur predominantly in low, long, relatively narrow ridges having rounded tops and gentle slopes. This type of ridge forms although the sillimanite is resistant to mechanical and chemical weathering. However, due to its fractured character steep ridges with bold outcrops do not form. An exception is the Smith-Cliff deposit where a stream cut away the toe of the hill, leaving prominent exposures.

The sillimanite-bearing rocks in Rutherford and Cleveland counties are confined to a zone about 12 miles wide. Northeastward the zone is narrower, being approximately 5 miles wide in the vicinity of South Mountains in Burke County. It has relatively regular boundaries in this area and the individual bands of sillimanite-containing rock are wider and more closely spaced. From the Catawba River northeastward to Dudley Shoals, the zone is composed almost completely of sillimanite schist with only occasional small lenses of granite or granite gneiss.

From Dudley Shoals northeastward the zone widens for a few miles and then breaks up into various bands which decrease in width rather uniformly northeastward into Wilkes and Iredell counties. Northeast of the point where the zone branches into individual bands, the schist is generally uniform in trend but contains a relatively low percentage of sillimanite. In this area it is possible to trace the individual schist bands with little difficulty.

The original reconnaissance survey<sup>3</sup> on sillimanite in this zone indicated that the sillimanite-bearing rock occurred in a shear zone. Field evidence collected during the current survey substantiates this observation. Individual shear zones vary up to several hundred feet in thickness and are readily evident by their fragmentary appearance. Evidence of shearing is present in many orders of magnitude, varying from minute intragranular shearing, seen only with the microscope, to large persistent fault planes which may



be traced for considerable distances along the outcrop. The commonest evidence of shearing is found in small fragments which have been dragged into somewhat sigmoidal shapes. The entire zone of sillimanite-bearing rock is highly fractured and contains extensively folded schists. Small thrust faults and closely spaced joints are numerous. In addition, local normal faults with small displacement occur.

In general, the individual bands of sheared sillimanite-bearing rock cut diagonally across the major belt, which trends from N 40° to N 60° E. These bands strike from N 20° to N 40° and dip about 20° SE, however, locally the dip steepens and may be as great as 50° SE. It is thought that local variations in trend are due to post shear folding which has warped the individual schist bands. Local northwest strikes were observed, especially in the Hollis-Casar area and northeast of Dudley Shoals.

The sillimanite schist is so thoroughly fractured that it breaks into elliptical shaped fragments or nodules ("buttons") which range up to 3 inches in length. These small nodules cover the surface at many places and are helpful in identifying and outlining the sillimanite-bearing zone, especially in areas where outcrops are rare.

A number of different rock types occur throughout the Cliffside-Elkin belt but, in general, the principal rock types are granite, granite gneiss, and quartz-biotite schist.

The rock in which sillimanite occurs is predominantly a quartz-biotite-sericite-sillimanite schist. Accessory minerals include garnet, graphite, chlorite, alum, pyrite, zircon, ilmenite, barite, and rutile. Near the surface biotite and pyrite have been oxidized and have stained the sillimanite rock. Sericite occurs in considerable quantity, locally composing approximately 50 percent of the schist. Pyrite, occurring in small amounts throughout the zone, was the only sulphide observed. It appears to be one of the late minerals. The other accessory minerals occur only in trace amounts, some of which apparently were original constituents. Some of these minerals were formed by metamorphism, and others by igneous solutions.

Small pegmatites and narrow quartz veins occur throughout the zone. The pegmatites, in general, average less than a foot in thickness and are rarely more than 4 feet long. The principal minerals in the pegmatites are quartz, feldspar, mica, and small amounts of tourmaline. Locally pegmatites compose as much as one-half of the sillimanite-bearing rock.

Hunter and White<sup>3</sup> who examined thin sections of the sillimanite-bearing rock described it as follows:

"Under the microscope the sillimanite-bearing rock is seen to be a quartz-biotite schist with very minor amounts of a plagioclase which appears to be albite. The bulk of the rock is quartz, which like the feldspar, seems to have been a component of the original. Both these minerals are allotriomorphic. Small euhedra of biotite are disseminated quite generally throughout the rock and locally garnets appear. Both these minerals probably represent original components of the rock.

"The sillimanite appears in needlelike crystals which replace the quartz, biotite, muscovite, and garnet. The crystals occur singly or in groups which take on several distinct patterns of aggregation. Sometimes they are in subparallel growth but following a sinuous line apparently determined by the previous position of the linear aggregates of muscovite crystals which they tend to replace, largely with the longest direction of the sillimanite parallel to the cleavage of the muscovite. Again, the bundles of sillimanite needles may be heterogeneously oriented in felted aggregates, or thinly disseminated in random orientation throughout the quartz. Of most importance, however, is the tendency for them to form bundles in parallel or sheaf-like growth to the virtual exclusion of all other minerals. Such bundles are usually small and sparsely distributed through the rock, but in some of the more favorable localities such as Smith Cliff on Prospect Ridge in Burke County they are larger and form a significant fraction of the rock, offering potentialities for development."

Granites occur on the southeast and northwest sides of the shear zone. These rocks show evidence of some deformation but not nearly so pronounced as the sillimanite-bearing rock. Two different granites occur throughout most of the length of the belt, both of which may be present at any one locality. These granites appear to be of different age and one at least is apparently post shear in age. No attempt was made to map the extent of either the granites and only a megascopic description is available. The most abundant granite contains a very high percentage of quartz and a small amount of mica and feldspar. It is fine-grained and, as a rule, makes poor outcrops. The other granite is coarse-grained, containing a rather high percentage



of microcline feldspar and relatively low percentage of mica and quartz. This granite occurs most frequently on the northwest side of the belt.

In the Dudley Shoals section an irregularly shaped area is underlain by the microcline granite, tongues of which protrude almost across the shear zone. At this locality the granite apparently is post shear in age and may be responsible for the higher grade sillimanite deposits which occur in the Dudley Shoals area.

The character of the parent rock of the sillimanite schist is not known. Field evidence, however, indicates that the original material from which the schist was formed was of sedimentary origin, that it consisted of quartzite interbedded with shale, and that the schistose layers now represent the metamorphosed equivalent of the original shaly facies.

### DESCRIPTIONS OF DEPOSITS

The following descriptions of individual deposits in the Cliffside-Elkin belt are in order from south to north. Considerable variance of sillimanite content and local conditions of geology are evident throughout the belt, and in the descriptions of individual occurrences these local variations are described.

#### Polkville Deposit

The Polkville deposit is located in Cleveland County, one mile N 30° E of Polkville, in a ridge about .2 of a mile from a secondary road (Map location 6, Plate 1). It can be reached by following the secondary road one mile northeast of Polkville. The deposit is on the north side of the road.

Considerable quartz-sillimanite schist and float pegmatite occur along the crest of the ridge, but no outcrops were found in which to study their relationship. Float schist sampled from the ridge contained 24.8 percent sinks\* (Laboratory sample 713-8). The sample was representative of the schist but did not include any pegmatite material, which, judging from the amount of float, probably makes up at least 1/3 of the rock. The richer schist may occur in narrow bands. Other samples of sillimanite-bearing rock collected from this locality and analyzed for sillimanite content included samples 713-12 to 14.

#### Wards Creek Deposit

This deposit, located in Cleveland County 5.2 airline miles N 55° E of Hollis and 3.9 airline miles N 8° W of Polkville, can best be reached by following highway No. 10 two miles north of Polkville, turning left and following secondary road .5 of a mile, turning right and following secondary road 2.2 miles (Map location 9, Plate 1). The deposit is in a ridge on the northwest side of the road.

Considerable float, both small nodules and schist, is found along the ridge. A few large nodules, similar to the Dudley Shoals type, were found along the ridge. Representative samples of float material taken along the ridge contained 33.2 percent sinks in heavy liquid concentration (Laboratory sample 713-2). Microscopic examination revealed the presence of sillimanite, barite, rutile, ilmenite, hematite, and zircon, with sillimanite constituting about 85 to 90 percent of the sinks. About 6 percent of the sinks was barite. Very little sericite alteration was observed.

The deposit is believed to offer the best possibilities for development of any deposit found in this area; however, due to the absence of outcrops only little detailed information could be obtained. The float may be representative of the underlying schist or may have been formed from rich pockets or small zones that was more resistant to weathering than the other material. Other samples studied from this locality include 713-1, 3 to 7.

#### Casar Deposits

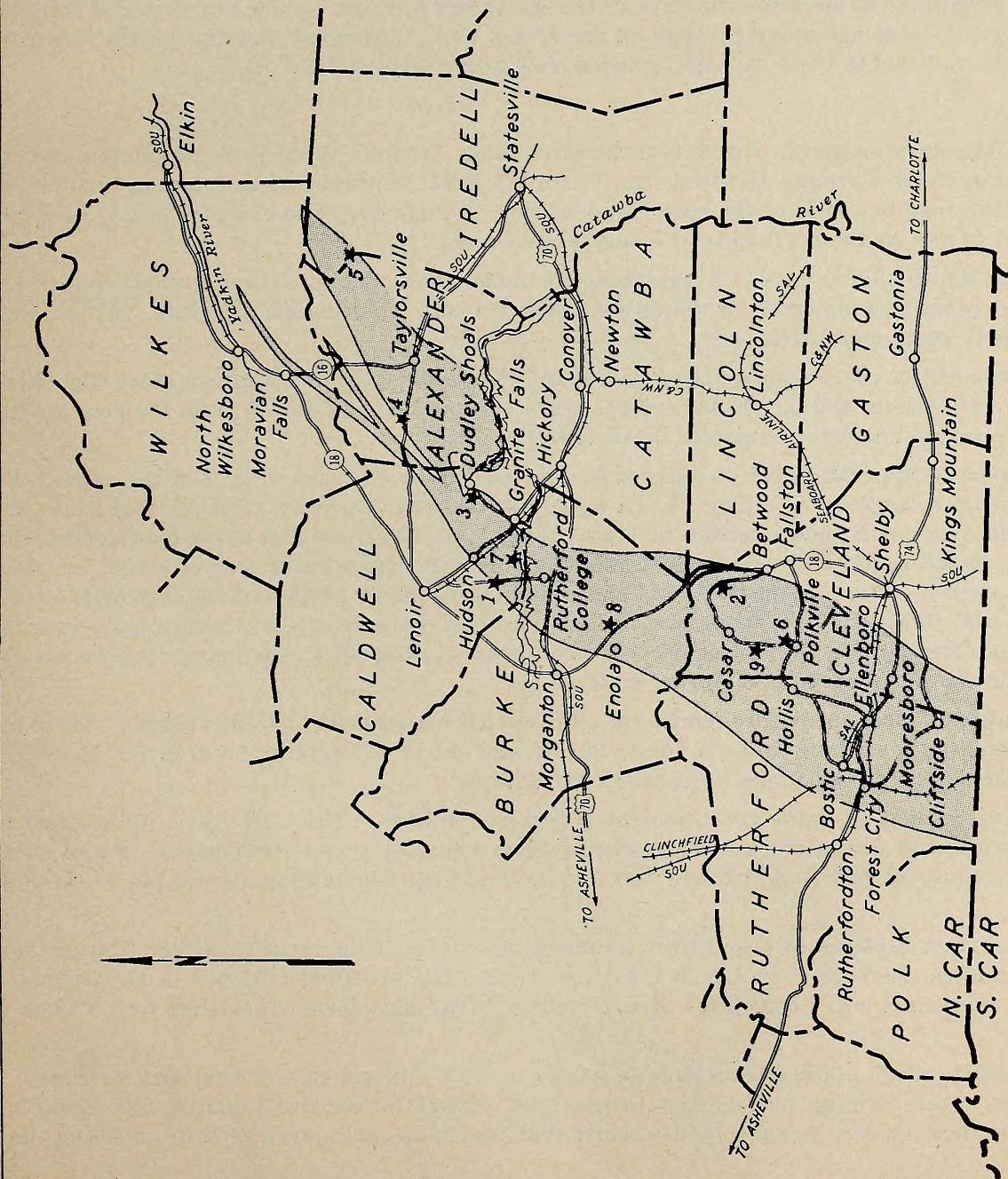
Two sillimanite occurrences have been noted in the vicinity of Casar. One is located 3.5 airline miles N 78° E of Casar and 3.7 airline miles N 39° W of Belwood. It can best be reached by following a paved highway 3.7 miles northwest from Belwood, turning left and following a secondary road 3.4 of a mile (Map location 2, Plate 1). The deposit is located 1/8 of a mile northwest of the road near several old mica mines. The other deposit is located one mile northwest of this locality in a large ridge adjacent to the road.

\*See Laboratory results.

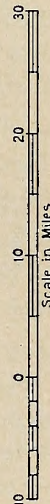


# EXPLANATION

- Zone Containing Principal Sillimanite Occurrences
- ★ Outstanding Sillimanite Deposits
- 1 Cages Mountain Deposit
- 2 Casar Deposit
- 3 Dudley Shoals Deposits
- 4 Ellendale School Deposits
- 5 Fox's Orchard Deposit
- 6 Polkville Deposit
- 7 Saw Mills Deposit
- 8 Smith Cliff Deposit
- 9 Wards Creek Deposit



OCCURRENCES OF SILLIMANITE IN  
CLIFFSIDE-ELKIN BELT OF NORTH CAROLINA





The first deposit occurs adjacent to heavily iron stained kyanite schist and near several sheet mica pegmatites. Because of poor exposures and insufficient time, the geological relationship of the several rock types was not studied in detail. However the occurrence is an unusual one since no appreciable amount of kyanite was found at any other locality in the Cliffside-Elkin sillimanite zone.

The sillimanite schist from both deposits is similar, being composed of very fine needles of sillimanite (fibrolite). The other minerals are predominantly quartz and sericite. The amount of iron stain appeared to be relatively low. Microscopic examination (Laboratory sample 713-10) of sinks in heavy liquid revealed the presence of sillimanite, ilmenite, barite, staurolite, rutile, zircon, and a few zircon inclusions. About 95 percent of the sinks was sillimanite with practically no alteration to sericite. Most of the remaining heavy mineral content was ilmenite.

Samples taken from outcrops and float schist from the two deposits contained 16.0 (Laboratory sample 713-10) and 16.4 percent (Laboratory sample 713-11) sinks, the former being from the deposit near the mica mines. The sample is believed to be representative of the schist, but does not include any material from the numerous small pegmatites that are found throughout the schist. It is estimated that the pegmatites make up from  $\frac{1}{4}$  to  $\frac{1}{3}$  of the material in these deposits (See also laboratory sample 648-C).

### Smith Cliff Deposit

The Smith Cliff deposit is located in Burke County, seven miles (airline) S 42° E of Morganton and can be reached by following North Carolina Highway No. 18 for 8.5 miles southeast of Morganton, turning left and following a country road one mile to the east (Map location 8, Plate 1). The cliff is about  $\frac{1}{4}$  of a mile to the north, adjacent to and on the north side of Henry Fork Creek.

The sillimanite at Smith Cliff occurs in a quartz-biotite-muscovite-sericite-sillimanite schist, quartz and biotite being the most prominent minerals in the unweathered schist. Tourmaline, graphite, garnet, feldspar, and pyrite occur in small quantities.

The schist forms a nearly continuous outcrop for 600 to 700 feet along the face of a very steep cliff (Plate 2). The cliff, which varies from 300 to 330 feet high, is very conspicuous and differs from the long narrow type ridge which generally underlies sillimanite deposits in the belt.

There is a relatively large fold (mostly obscured by overburden) in the eastern part of the deposit, the axis of which extends up a large draw (Plate 2). A basic dike occurs in the draw near the fold axis. The schist west of the fold axis has a general strike of from N 30° E to N 60° E and east of the axis strikes from N 30° W to N 60° W. Small gentle folds are found throughout the cliff, but no area was observed in which intensive crinkling occurred. West of the fold axis and including the major portion of the deposit, the rocks dip from 15° to 25° NW into the ridge, while the rocks in the eastern part dip northeastwardly into the ridge at about the same angle. Much of the schist had two planes of schistosity, one being roughly parallel to the dip of the beds, the other varying at angles up to 45°.

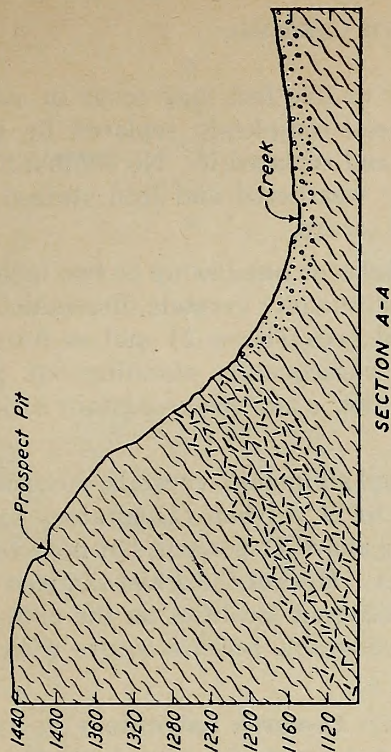
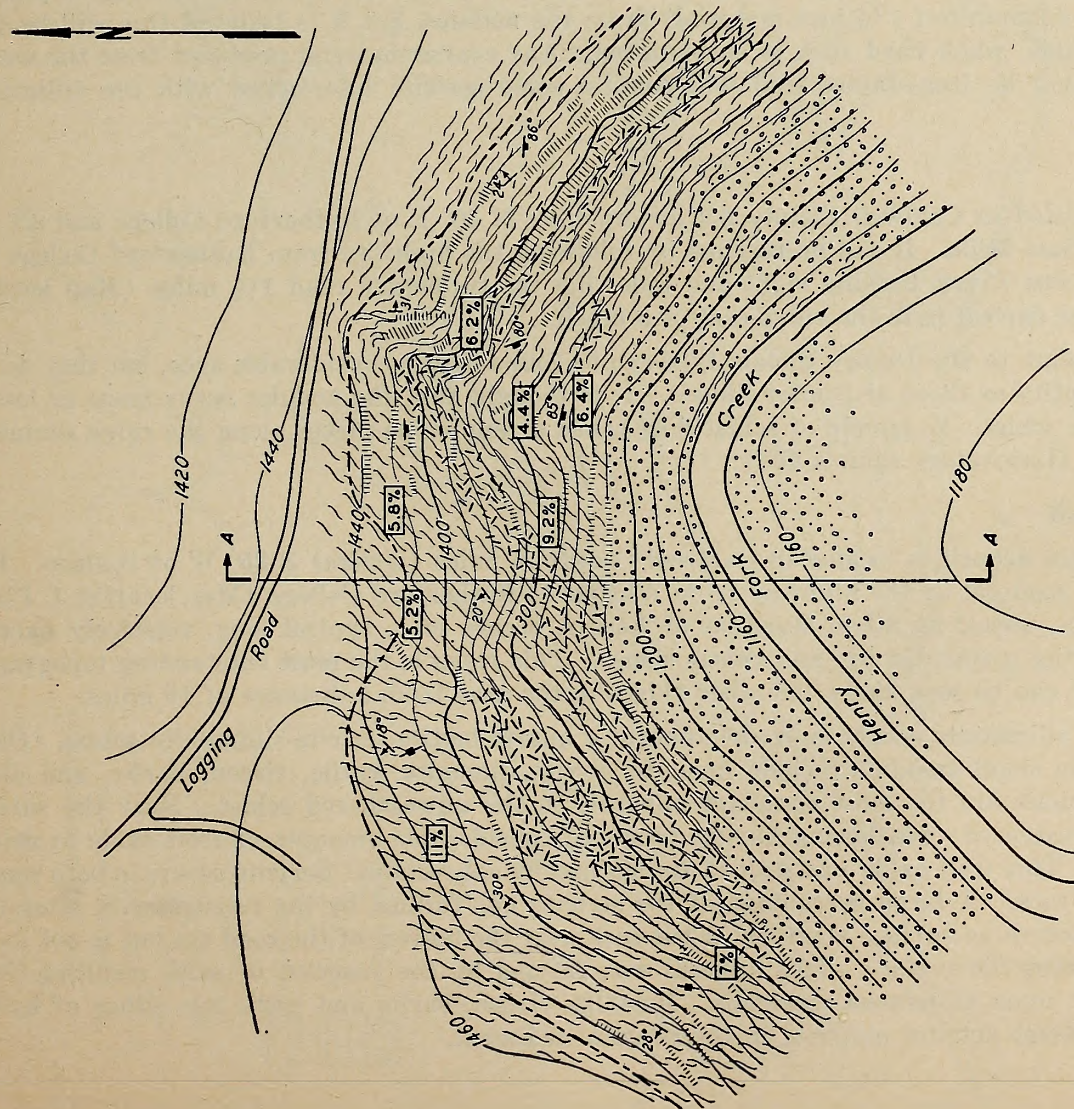
Joint surfaces are very prominent throughout the cliff, some being from 30 to 35 feet across. There are two major joint systems—one striking from N 15° to 20° W and the other striking from N 40° to 45° E; other minor joint systems occur. All joints have near vertical dips.

A characteristic of the deposit is the great amount of igneous activity. This activity is represented by granite, small pegmatites and granitized schist; gradation from schist to granite is common. Small lenses of granite seldom exceeding 25 feet in width and 100 feet in length are found at numerous places throughout the deposit.

Small pegmatites, from 3 inches to over 3 feet wide and several feet long, occur as *lit par lit* injections. These pegmatites, in places, compose from  $\frac{1}{5}$  to  $\frac{1}{3}$  of the rock. The principal minerals in the pegmatites are quartz, feldspar, mica, and small quantities of tourmaline. The mica books range up to 3 inches in diameter.

The granitized schist, which approaches a granite gneiss in both mineral composition and structure, is found in many places, often forming near-vertical ledges that extend for several hundred feet along the face of the cliff. This rock appears to have been a schist that was saturated and altered by invading igneous solutions.

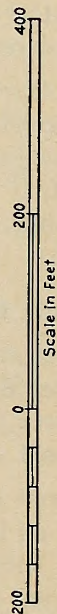




#### EXPLANATION

- Sillimanite Schist
- Granitized Schist
- Granite
- Talus and Residual Soil
- Edge of Cliff
- Vertical or Near Vertical Ledges
- Strike and Dip of Schist
- Strike and Dip of Joints
- Percent "Sinks" (Heavy Liquid Determination)
- Contour Line

### SMITH CLIFF SILLIMANITE DEPOSIT BURKE COUNTY, NORTH CAROLINA



Geology by Lewis J. Hash  
June 1945



Lenses of quartzite seldom over three feet wide and four or five feet long occur in many places over the face of the cliff. Some of the quartzite appears to have been completely replaced by granite. Other quartzite shows evidence of granite having partially invaded and replaced it. No sillimanite was observed in the quartzite. The rock along the top of the ridge is highly weathered and iron stained, but in places, 100 feet or more down the cliff, relatively unweathered material occurs.

The sillimanite in this deposit occurs in two forms—as nodules or bundles up to two inches in diameter, which are composed of many small crystals, and as individual sillimanite crystals disseminated through the schist. The nodules are conspicuous in and near the prospected area (Plate 2) and as float along the top of the ridge. These nodules are very resistant to weathering, consequently standing out and giving the rock a “knotty” appearance. Some are practically pure sillimanite, while others contain sericite interlocked with the sillimanite grains and are badly iron stained.

The largest quantity of sillimanite occurs as small individual sillimanite crystals, disseminated throughout the schist. The sillimanite content of the schist ranges up to 11 percent (Laboratory samples 660-1 to 8). Locally, areas are found in which the sillimanite content is above 11 percent, but none contained a minable quantity of ore. The rich areas occur along fracture zones. Most of the schist sampled contained from five to seven percent sillimanite; however, two samples from different localities on the cliff, representing a substantial quantity of ore, contained 9.2 and 11 percent. Considerable sericite occurs with the sillimanite in this deposit.

Flotation work at the North Carolina State College Minerals Research Laboratory in Asheville showed that a good sillimanite product can be prepared from this ore, but recoveries were low. It may be possible to produce some coarse sillimanite ( $+1/4$  inch material) from the nodules, but it is believed this will be very difficult, if not impossible, when hard rock is encountered. Any coarse material produced from the weathered schist probably will be iron-stained and will contain some sericite interlocked with the sillimanite crystals.

#### **Saw Mills Deposit**

This deposit is located in Caldwell County 3.3 airline miles N 30° E of Rutherford College and 2.7 airline miles S 35° W of Saw Mills. It can be reached by following the highway from Rutherford College one mile north of the Catawba River, turning right and following the secondary road  $1\frac{1}{2}$  miles (Map location 7, Plates 1 and 3). The deposit is in the ridge east of a creek.

Large nodules similar to the Dudley Shoals type can be found over a considerable area, but they do not exist in as large a quantity as those at Dudley Shoals. It is thought that the nodules occur more or less at random throughout the schist. A sample of schist float taken at numerous places along the ridge contained 9.4 percent sillimanite (Laboratory sample 686).

#### **Cages Mountain Deposit**

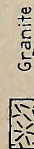
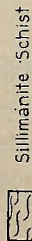
The Cages Mountain deposit is located in Caldwell County, 6 miles (airline) S 25° W of Hudson. It is well exposed in a deep road cut on the highway from Whitnel to Rutherford College (Map location 1, Plates 1 and 3). The property, owned by Silvio Martinat of Lenoir, occurs on a typical long, relatively narrow, “sillimanite ridge” having a rounded top and gentle slopes. This ridge is the most outstanding topographic feature in the area and can be seen above the other ridges in the area from a distance of 15 miles.

The rock in which sillimanite occurs is predominantly a quartz-biotite-sericite-sillimanite schist. Other minerals which occur in small amounts include ilmenite, pyrite, limonite, rutile, zircon, barite, and alum. Quartz, biotite, and sericite are the most abundant minerals in the unweathered schist. Near the surface biotite is thoroughly weathered; weathering having produced considerable amounts of iron oxide to depths of from 20 to 30 feet. This iron oxide has stained the sillimanite appreciably. Sericite occurs in both weathered and unweathered rock. A large percentage of the sericite has formed by the retrogressive alteration of sillimanite. Alum occurs as surface coatings in the rock near the bottom of the road cut but is not found in weathered material near the surface. This mineral was formed by the reaction of acid, resulting from the oxidation of pyrite, upon aluminous materials. Ilmenite, zircon, barite and rutile are either of hydrothermal origin or represent detrital material in the original sediment.



# EXPLANATION

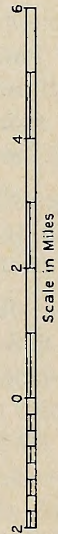
- 1 Outstanding Sillimanite Deposits
- 3-I Cages Mountain Deposit
- 3-II Dudley Shoals No. I Deposit
- 3-III Dudley Shoals No. II Deposit
- 7 Dudley Shoals No. III Deposit
- 7 Saw Mills Deposit



Sillimanite Schist  
Granite  
Granite and Granite Gneiss



VALDESE-DUDLEY SHOALS SILLIMANITE AREA  
BURKE, CALDWELL, ALEXANDER COUNTIES, NORTH CAROLINA





The schist has a general east-west strike but local variations from N 15° W to N 55° W occur. It generally dips from 15 to 30° to the south, however, where intensively folded, dips to the north occur. The most intensively folded area is immediately south of the quartzite lenses (Plate 4). Both north and south of the quartzite zone, the folds become broader, with limbs dipping approximately 30°.

Two joint systems are conspicuous in the road cut; the individual joints strike N 25° W and N 45° W, having dips of approximately 80° SW. The joints are spaced at intervals of 2 inches to 3 feet. Many joint surfaces 4 to 5 feet across are exposed. In addition to the joint systems and folds a normal fault striking parallel to the ridge and dipping nearly vertical is exposed in the road cut. This fault has a small amount of gouge in the zone of movement, however, it is not thought that the displacement is large, thus it has little significance in the geology of the deposit.

In addition to the sillimanite-bearing schist, other exposed rock types include quartzite, pseudo-diorite, quartz veins, and pegmatites (plate 4). The quartzite is a relatively massive and conspicuous band in the road cut. Pseudo-diorite occurs as lenses in the schist adjacent to the quartzite and probably represents the replacement of originally limey lenses by siliceous material. Quartz veins and pegmatites are numerous, ranging up to one foot in width and 5 to 6 feet in length. Small pegmatites, approximately one inch in width have invaded the schist both as *lit par lit* and as crosscutting bands. The pegmatites and quartz veins are more numerous in the intensively folded zone.

Except in the road cut the only exposures of bed rock are along a small valley near the east end of the ridge. These outcrops are narrow and highly weathered, revealing little geologic information. Considerable sillimanite schist float occurs along the ridge, fragments varying in size from two or three inches to a foot or more in diameter. Firm rock should be encountered throughout most of the ridge at depths from 10 to 15 feet.

The sillimanite in this deposit occurs as small nodules up to 1/4 inch in length and as individual crystals disseminated throughout the schist. The nodules are composed of many small interlocked sillimanite crystals, so that only fine concentrates can be produced from this ore.

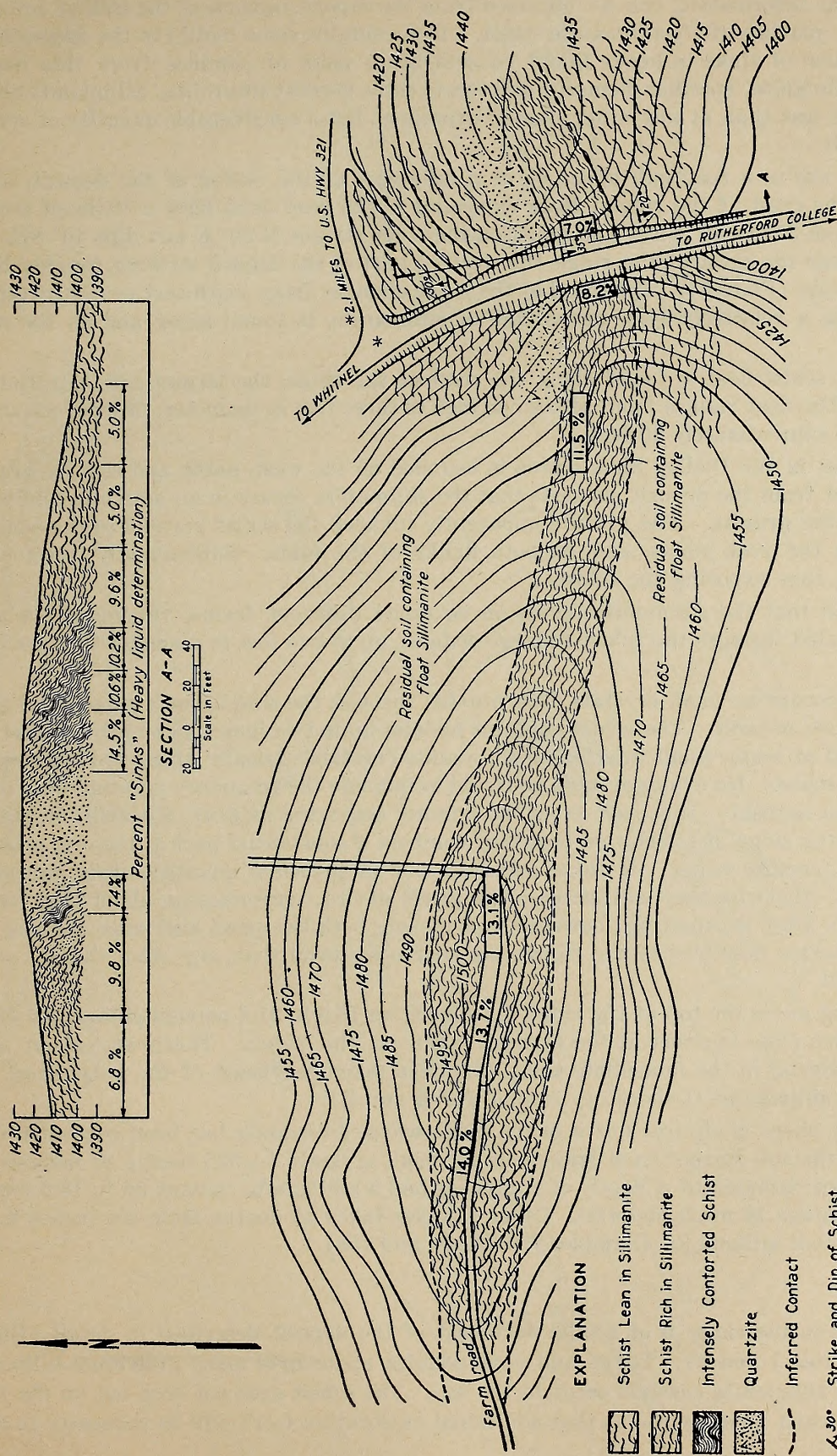
The sillimanite content of the schist varies from 5 to 14.3 percent (Plate 4) (Laboratory samples 648-D and H, 668-B to F, 669-1 to 9). Microscopic examination of the concentrates made from the ore reveals that up to 60 percent of the sillimanite crystals are partially altered to sericite. The schist with the highest sillimanite content is immediately south of the quartzite body at approximately the center of the road cut. A zone 80 feet wide contains 10 to 15 percent sillimanite. It is noteworthy that the most intensively folded and intruded zone contains the highest percentage of sillimanite. The sillimanite content decreases rather uniformly on both sides of this rich zone. Samples of float sillimanite schist taken at random along the crest of the ridge over an area 50 feet wide and 400 feet long varied in sillimanite content from 11.5 to 14 percent. Float samples taken from above the road cut on either side of the road contained 8.2 and 7 percent, respectively, while samples of bed rock taken at the bottom of the road cut directly below at a depth of approximately 35 feet contained from 10.2 to 14.5 percent sillimanite. Since sillimanite is a mineral very resistant to chemical weathering, the reasons for this variation in sillimanite content is not clear, but should this same proportion hold true for the crest of the ridge, the schist underlying it should contain above 20 percent sillimanite. Some prospecting will be necessary to determine accurately the percentage, quality, and quantity of sillimanite near the crest of the ridge.

Because of the mixed sillimanite and sericite and the difficulty of separating the two minerals, a pure sillimanite concentrate has not been prepared from this ore. If a mixture of sillimanite and sericite can be used by the ceramic or refractory industries, an ample tonnage of ore can be obtained from this deposit.

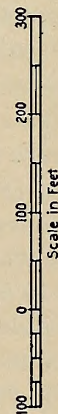
#### Dudley Shoals No. I Deposit

The Dudley Shoals No. I deposit is located in Caldwell County, four and one-half miles airline N 21° E of Granite Falls, and one and one-half miles airline S 79° W of Dudley Shoals (Map location 3, Plates 1 and 3). It can be reached from Dudley Shoals by following the secondary road leading to Cedar Valley one mile west, turning left and following a secondary road for one-half mile. The deposit is located south of the road on the property of Gather Teague, Dudley Shoals.





# CAGES MOUNTAIN SILLIMANITE DEPOSIT CALDWELL COUNTY, NORTH CAROLINA





Little detailed structural information can be obtained from the deposit because of the lack of outcrops. The sillimanite occurs in a quartz-sericite-sillimanite schist, which contains some biotite in the unweathered zone. Microscopic examination of sinks in heavy liquid concentration tests of samples from this deposit revealed the presence of sillimanite, specular hematite and two to three percent staurolite. Sillimanite alteration to sericite apparently is less than at any other deposit examined, but a considerable quantity of sericite is found locally in the deposit.

The outcrops examined are in a road cut, about  $\frac{1}{3}$  of a mile east of the center of the deposit, and a small outcrop northeast of the crest of the ridge. Rock exposures in the road bank have a strike of from N 5° E to N 20° E and dips from 35° to 40° SE. The schist on the ridge strikes N 20° E and dips 40° SE. The rock appears to be folded near the crest of the ridge, the western part of the deposit striking roughly N 70° W and dipping to the southwest (Plate 5). The trend of the ridge changes from southwest to northwest and considerable float, containing a relatively high percentage of sillimanite, is found along and on the north side of the ridge.

Considerable sillimanite schist float is found along the crest of the ridge, the largest concentration being near its highest point. The float ranges from pieces one inch to three feet in diameter. Firm rock should be encountered at a depth of approximately 20 feet.

Sillimanite-bearing schist in the Dudley Shoals area is bounded on the west, north and east by granite. Evidence which was obtained from the deposit suggests that the sillimanite occurs in an anticline fold which plunges to the north under the granite. The granite apparently invaded the schist parallel to the schistosity, completely assimilating the rock above and on both flanks of the folds. Subsequently, erosion has removed part of the granite, thus exposing the schist.

This deposit is unique in that the sillimanite occurs in so many different forms, varying from small needle-like crystals disseminated through the schist to large nodules, up to two feet in diameter that are practically pure sillimanite.

Most of the sillimanite occurs as small crystals disseminated through the schist, but a substantial quantity of coarser material is also present. The schist contains nodules up to two inches in length and one inch in width which are composed of many small interlocked sillimanite crystals. Locally, these nodules compose from 40 to 50 percent of the schist. No evidence could be found to indicate the frequency of occurrence of the large nodules (up to one foot across). However, from the number occurring as float, especially in the soil along the northeast slope of the ridge, it is believed that they compose a substantial part of the ore, probably occurring close together in fracture zones. If these nodules occur in sufficient quantities they can be recovered as coarse sillimanite; otherwise they will increase the grade of ore. Information about their occurrence can be determined only after prospecting; however, considering both the small and large nodules, this deposit is believed to offer better possibilities for recovering coarse material than any other deposit examined in the Cliffside-Elkin belt.

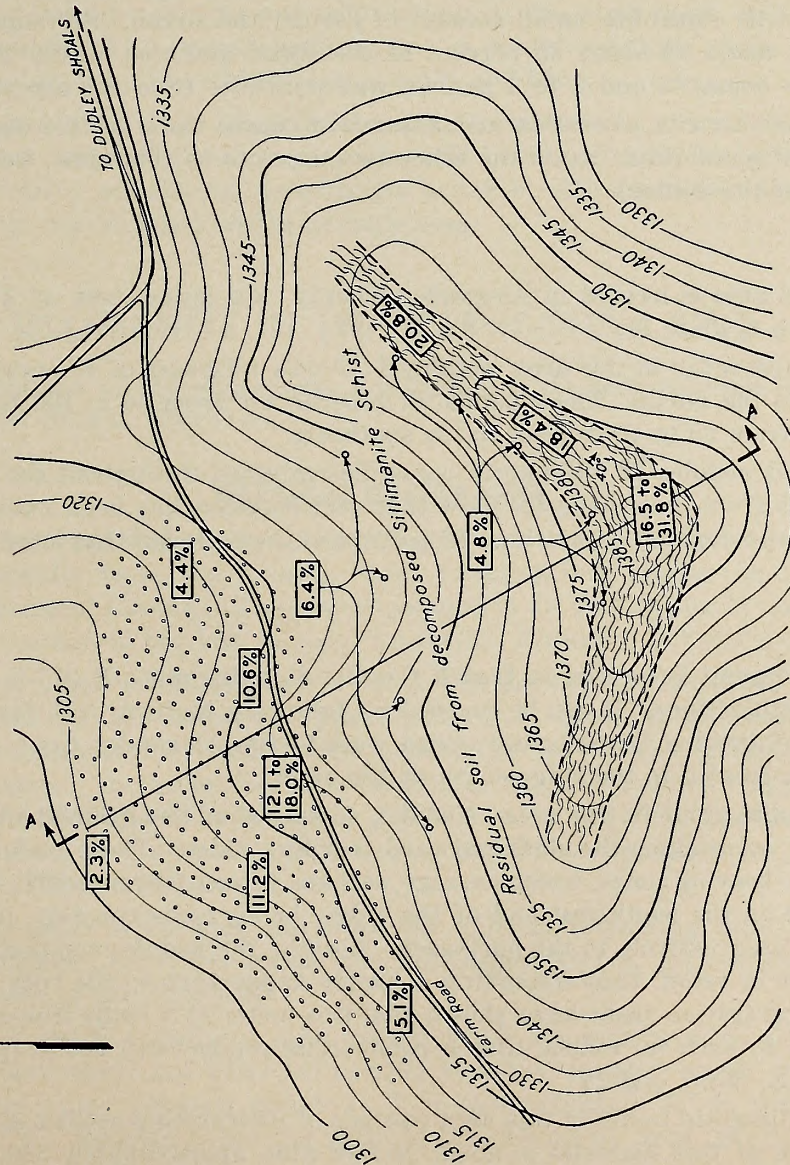
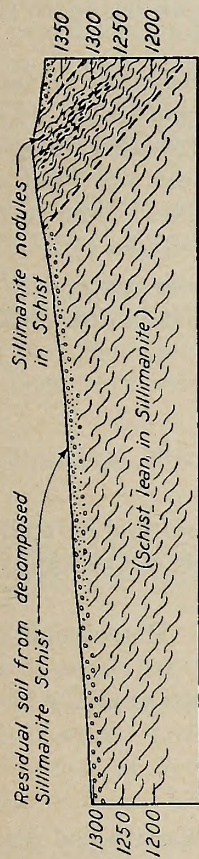
The schist float occurring along the top of the ridge contains from 16.5 to 31.8 percent sillimanite (Plate 5). These samples were taken close together at the highest point on the ridge. There are about equal amounts of both types of material in the immediate area. Samples taken northeast of the ridge crest contained 18.3 and 20.8 percent sillimanite (Laboratory sample 707-A and B).

In addition to the schist, there is an area north of the ridge where sillimanite has been concentrated in the soil. The sillimanite in the soil ranges from fragments of small crystals (—325 mesh) to nodules two feet or more across. Surface samples to a depth of six inches had a sillimanite content up to 18.0 percent (Plate 5), about half being minus 16 mesh material. Other samples taken at depths from six inches to five feet contained up to 6.1 percent sillimanite (Samples 730-732-E, and 758).

## Dudley Shoals II

Sillimanite schist occurs in the ridge .5 of a mile northeast of the deposit described in detail (Dudley Shoals I, Map location 3, Plates 1 and 3). Large and small nodules, made up of many individual sillimanite crystals, and minus 16 mesh sillimanite crystals occur in the soil. The schist does not crop out on the ridge and only a small amount of schist float occurs, so that additional exploration work will be necessary to accurately appraise the deposit.

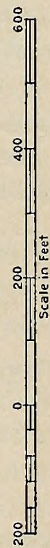




# EXPLANATION

- Schist Lean in Sillimanite
- Schist Rich in Sillimanite
- Concentration of Nodules and Fine Sillimanite in Soil
- Three Feet Deep Drill Holes in Residual Soil from Decomposed Sillimanite Schist
- Inferred Contact
- Strike and Dip of Schist
- Percent Sillimanite (Heavy Liquid Determination)
- Contour Line

## DUDLEY SHOALS NO. 1 SILLIMANITE DEPOSIT CALDWELL COUNTY NORTH CAROLINA





Large nodules, up to three feet across and weighing two or three hundred pounds, are present. Numerous rockpiles found along the edges of fields contain 50 percent or more large sillimanite nodules. The nodules are found throughout an area extending for approximately one-half mile southeastward from the road. Several tons of nodules could be collected from this area.

In addition to the large nodules, small nodules and fine sillimanite have been concentrated in the soil by weathering and erosion. A surface sample, taken over an area of approximately 50 feet by 200 feet, contained 10.7 percent sinks. This deposit has not been sampled in detail, but it appears to contain a concentration of sillimanite in the soil all along the ridge which is approximately  $\frac{1}{4}$  of a mile long and several hundred feet wide (Samples 708-A and 732-F).

### Dudley Shoals No. III

Another promising deposit in the Dudley Shoals area is located approximately  $\frac{1}{3}$  of a mile southwest of the Dudley Shoals No. II deposit (Map location 3, Plates 1 and 3). The deposit occurs on the south side of a small stream in a relatively steep-sided ridge.

There is considerable sillimanite schist float along the ridge, which is covered by timber, but no large nodules occur. Samples of schist float taken at random along the ridge contained 20.8 percent sinks. (Laboratory Sample 708-B). Microscopic examination of sinks in heavy liquid concentration revealed the presence of sillimanite, hematite, staurolite, small amount of garnet, and zircon. Sillimanite, about 5 to 7 percent being altered to sericite, made up about 85 percent of the sinks, and was mostly needle-like. Nine to ten percent of the sinks was hematite and 2 to 3 percent was staurolite (See also samples 707-C and D).

Because of the higher sericite alteration and absence of coarse material this deposit does not appear to offer as great commercial possibilities as do the other two deposits in this area; however, it is noteworthy because of its high sillimanite content.

### Ellendale School Area

The Ellendale School area is located in Alexander County, six miles west of Taylorsville, adjacent to highway 90 (Map location 4, Plate 1).

Several bands of schist occur in this area, notably  $\frac{1}{10}$  of a mile east of Ellendale School and extending for three or four miles to the north. These bands, in general, are from 50 to 100 feet wide, strike approximately N 30° E and dip from 20 to 40 degrees to the southeast.

Both fine needles and nodules of sillimanite occur disseminated throughout the schist. Microscopic examination of concentrates from these deposits show that sericitization has been extensive. In places it appears that sillimanite once composed as much as 50 percent of the rock, but that later solutions altered a large part of it to sericite.

### Fox's Orchard Deposit

The Fox's Orchard deposit is located in Iredell County, 8 airline miles N 37° E of Hiddenite and 4 airline miles N 32° E of Smith's Store. It can be reached by following highway 115 four miles south from the Wilkes County line, and following the secondary road west to the Alexander County line (Map location 5, Plate 1). This deposit is located in the ridge south of the road.

Two types of sillimanite occur in this area. Nodules, composed of fine-grained sillimanite and sericite up to two inches in diameter, occur along the northeastward trending ridge. These nodules occur as zones in a quartz gneiss. The nodule-bearing zones, which average perhaps fifteen feet in width, strike to the northwest. Zones are thickly spaced on the southwest end of the ridge, being approximately 100 feet apart in places, with the space widening progressively to the northeast. Locally, the nodules compose as much as 50 percent of the rock, standing out in relief, thus imparting a knotty appearance to the rock. Microscopic examination and laboratory concentration tests have shown that this material is badly iron-stained, and that sericite alteration has developed to such an extent that a commercial product can not be made from the ore. (See Laboratory samples 648-E, 662-1 and 2).

The other type of sillimanite found in this area consists of interlocking needles associated with large garnets. The principal zone of this material is about 50 feet wide, approximately 300 feet long, and is located



on the north side of Rocky Creek. The sillimanite content varies considerably. It is very fine-grained and appears to have no commercial value.

#### Wilkesboro-Taylorsville Area

The sillimanite schist in this area, the northeastern part of the belt, consists of long, narrow bands striking from N 30° E to N 80° E. Although locally the strike of the schistosity varies considerably, striking northwest in many places, the individual bands are generally uniform in both width and trend. The bands vary from a few feet to several hundred feet in width, and are usually from one to three miles apart; the most abundant country rocks are granite and granite gneiss.

Most of the samples from this area were collected from road cuts. The sillimanite content of individual bands appeared relatively uniform over considerable areas. The locations and sillimanite contents of some of the more promising deposits are as follows:

A deposit, located in Wilkes County and outcropping in the road bank on Highway 16 on northern slope of the Brushy Mountains, is about 50 feet wide and can be traced easily through the mountain by the float schist. A sample taken from the road cut contained 12.7 percent sillimanite and a sample of float schist from the ridge northeast of the road contained 12.2 percent sillimanite (Laboratory samples 696-A and B).

A deposit, located in Alexander County and outcropping in the road bank on highway 16, four miles south of Taylorsville, contained 11.0 percent sillimanite. A sample of high grade float from this deposit contained 17.7 percent sillimanite (Laboratory samples 694 and 695).

Numerous other samples taken from the Wilkesboro-Taylorsville area contained under 10 percent sillimanite. It is probable that better deposits in this area will be found; however, geological conditions indicate that the chances of finding commercial deposits are better in other sections of the zone. Sericitization has been very extensive in the Wilkesboro-Taylorsville area.

### SILLIMANITE IN THE WARNE-SYLVA BELT

The following descriptions of the sillimanite occurrences in the zone between Warne and Sylva, North Carolina, were prepared by Earl C. Van Horn.

#### PHYSICAL GEOGRAPHY

The sillimanite-bearing rock designated as the "Warne-Sylva belt" occurs in a more or less continuous zone trending northeastwardly from the Georgia-North Carolina line, across Clay and Macon counties to the vicinity of Sylva in Jackson County. The major population in this region is concentrated in the more fertile valleys. Towns adjacent to the belt include Hayesville, Franklin, Dillsboro, and Sylva.

U. S. Highway 64 traverses the Warne-Sylva belt in the vicinity of Hayesville in Clay County. State highway No. 28 crosses the belt northwest of Franklin, and U. S. Highway 23 crosses the belt east of Dillsboro. Secondary roads, adequate for truck traffic, provide access to most of the area. A branch line of the Southern Railroad extends to Hayesville from Andrews, North Carolina. Franklin is provided rail transportation by the Tallulah Falls Railroad which joins the main line of the Southern at Cornelia, Georgia. The northern end of the belt, in the vicinity of Dillsboro and Sylva, is served by the Asheville-Andrews-Murphy Branch of the Southern Railroad.

Major streams which occur in the area and cross the sillimanite-bearing zone include, from south to north, the Hiwassee, Nantahala, Little Tennessee, and Tuckasegee Rivers. Tributaries of these streams provide adequate water to most of the deposits.

Climatic conditions of the Warne-Sylva area are favorable for mining during most of the year, however, during the winter light snows and extended periods of rainy weather would interfere with open cut operations. Temperatures range between minus 5° F. to approximately 95° F. with an average temperature of approximately 60° F. Rainfall is heavier than in the Piedmont area, averaging approximately 60 inches per year.



Major mountain ranges which traverse or parallel this sillimanite belt include Davy and Cherry Mountains, which reach elevations of approximately 2,900 feet; Nantahala Mountains which have elevations of approximately 5,000 feet; and Cowee Mountains which reach elevations of approximately 5,000 feet. Association between topography and the sillimanite-bearing rock is not evident in the field.

### GEOLOGY

Sillimanite is known to occur in two slightly different settings in western North Carolina. The most important sillimanite occurrences are in a well defined belt, up to 4,000 feet wide, extending from near Warne, in Clay County, northeastwardly through Clay and Macon Counties to Sylva in Jackson County. The occurrences between Warne and Sylva are referred to in this report as the "Warne-Sylva sillimanite belt."

Of apparently lesser importance are erratic occurrences of sillimanite near Grassy Ridge and Big Ridge mica mines south and southwest of Waynesville in Jackson and Haywood Counties, on the north tip of Ripshin Mountain near the headwaters of South Hominy Creek in Buncombe County, and in the Mars Hill area of Madison County. Sillimanite of rather low concentration occurs in these isolated localities in a garnet-biotite gneiss. The host rock is moderately massive but a pronounced schistosity usually is present.

The belted alignment of the Warne-Sylva sillimanite belt is at only slight variance with the regional geologic mapping of Keith<sup>5</sup> (1907), since it parallels roughly the formational trends which Keith showed. In certain localities, particularly in the western part of Macon County, the sillimanite belt does cross several of Keith's boundaries. The geology of the region, however, is characterized by transition and lithologic similarity, so that slight difference of interpretation and classification are of little consequence. The nearly straight trend of the sillimanite belt, even when confined to a single formation, is somewhat unusual for the region, and slip cleavage control in a fault zone is not improbable.

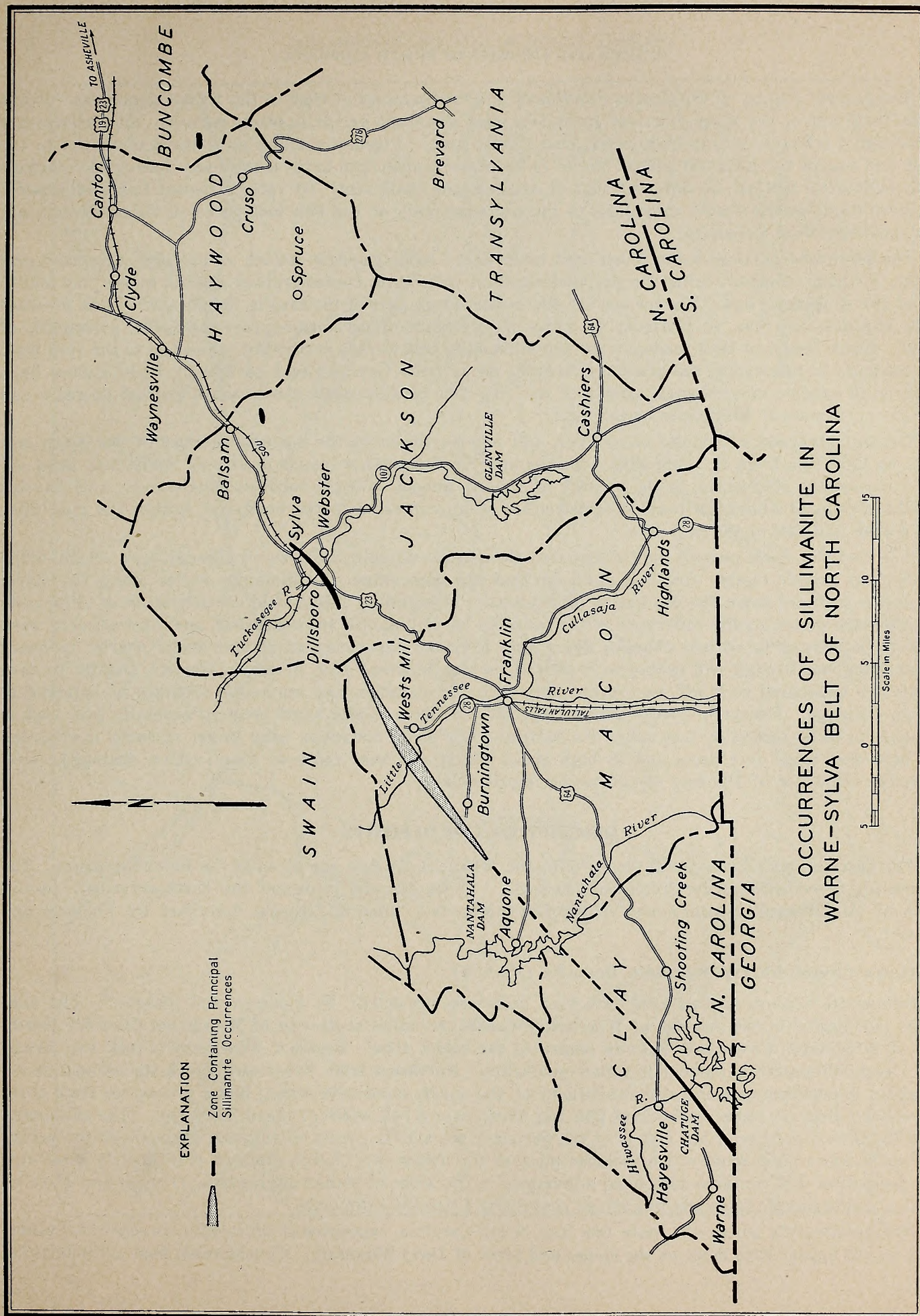
The Warne-Sylva sillimanite belt is mostly a part of the series which Arthur Keith mapped as Carolina gneiss<sup>4</sup> (1901). Locally this rock includes quartz-mica schist and gneiss, garnet-mica schist, garnetic and hornblende quartz gneisses, "graywacke," and banded granite gneisses. Any of these rock types may be graphitic in places. Pegmatite material may be present as migmatite and as dikes, veins, and pods. The mineral content of the sillimanite-bearing rock includes muscovite, hydromica, biotite, chlorite, hornblende, quartz, feldspar, kyanite, sillimanite, staurolite, garnet, magnetite, ilmenite, rutile, titanite, brown tourmaline, clinozoisite, epidote, zircon, and barite. The rock has been metamorphosed extensively, and is characterized by well developed schistosity and crenulations, and major and minor intra-formational faults.

In the Hayesville area, immediately northwest of the sillimanite belt, is a very old granite complex which Keith<sup>5</sup> mapped as Archean granite. This complex possibly was a biotite granite which has been metamorphosed to granite gneiss and feldspathic schist and in many places is now indistinguishable from the rock mapped by Keith as Carolina gneiss. At some distance to the southeast of the sillimanite belt, zones of dark hornblende gneiss occur. Locally, masses of pyroxenite and peridotite rock occur in association with the hornblende gneisses. Sillimanite apparently is not related in any way to either the hornblende gneiss or to the ultra-basics.

The granite complex which occurs northwest of the sillimanite belt in the Hayesville area is not present in the Tusquitee-Burningtown area but quartzose rock of the Great Smoky formation<sup>5</sup> occurs along the northwest side. Hornblende rocks are near the southeast side of the belt. In other respects the geology is much the same as that described in the Hayesville area.

Published data on the general geology of the Etna-Cowee area are not available. All of the rock types seem to intergrade, thus geologic mapping on a reconnaissance scale is of little specific value to the present studies. Locally the rocks of the area include quartz-mica gneiss and schist, granite gneiss, garnet and kyanite gneisses and schists, "graywacke," hornblende gneiss, pegmatite, and, in one locality, meta-amphibolite. Granites occur some distance away, both to the north and south. The sillimanite belt is associated with all but the granite, hornblende gneiss, and "graywacke." Metamorphic characteristics are little different from similar rocks to the southwest, there being crenulations, several ages of cleavages, and a well developed regional schistosity. Strikes and dips are irregular locally. Average strikes are N 50° E in the Etna vicinity and N 60° E near the Cowee Mountains.





OCCURRENCES OF SILLIMANITE IN  
WARNE-SYLVIA BELT OF NORTH CAROLINA



The general geology of the Greens Creek area is a continuation of that in the Etna-Cowee area. Rocks within the limits of the sillimanite belt are quartz-mica schist and gneiss, in places garnetic, but with a larger proportion of schistose phases than in the Etna-Cowee area. Pegmatite material is more abundant in the schist and except for local variations biotite is less conspicuous than to the southwest. Associated minerals in the sillimanite belt are no different than in areas to the southwest. Of rocks adjacent to the sillimanite belt, hornblende gneiss occurs very close to the southeast side of the belt and rocks to the northwest are more quartzitic than elsewhere.

The southwest portion of the Sylva area involves the same geologic setting as has been described previously, a single exception being the preponderance of very hard, coarse-grained granite gneiss just southeast of the sillimanite belt. The geology of the northeastern part of the area is complicated by the presence of the Webster ring dike, an intrusion or series of intrusions of peridotite-pyroxenite rocks, principally of dunite. There seems to be a tendency for the sillimanite belt to veer northward tangential to the ring dike. This tendency is reflected in the gradual change in strike from Greens Creek to Sylva. Field studies have not revealed specific mineralogical effects of the ring dike on sillimanite other than a gradual decrease and final disappearance of sillimanite occurrences.

The last observed sillimanite occurrence, 400 feet northeast of the northeast corner of the Sylva city limits, is 1300 feet from the ring dike. Sillimanite-free feldspathic quartz-muscovite schist has been observed beyond the sillimanite, in the vicinity of Liberty School. Considerable reconnaissance study has not revealed additional sillimanite-bearing schist either in an extension to the northeast, within the ring dike, or in a drag fold east of the ring dike.

It is doubtful, from present indications, that the quality of sillimanite in weathered rock would differ greatly from that in fresher rock. It is known that the percentage of sillimanite varies along the strike and similar changes down the dip are to be expected. Discounting mechanical concentration of sillimanite in overburden material, any difference in the quantity of sillimanite in weathered and unweathered rock would be attributed to normal changes down dip. Previous experience in similar rocks nearby indicates that chemical weathering will extend to depths of several hundred feet in many places. Depths to firm though still weathered rock will vary principally with the elevation and horizontal distance as referred to present drainage. Except in places where large streams have caused rapid erosion, generally firm rock is estimated to be 30 feet to 60 feet below the surface. For short distances, near larger streams, overburden may be 5 feet to 20 feet deep, and in high areas which are well removed from active drainage, overburden on the order of 100 feet would not be improbable.

### DESCRIPTIONS OF DEPOSITS

The descriptions of sillimanite deposits in the Warne-Sylva belt are given in the following pages. The deposits are described in order from south to north. These deposits represent the northeastwardly continuation of the sillimanite occurrences in the Davy Mountain area of Georgia described by Furcron and Teague.<sup>2</sup>

#### Brasstown Church-Cherry Mountain Deposits (Plate 6)

Sillimanite deposits in this area have been described previously by Furcron and Teague.<sup>2</sup> The sillimanite belt begins in the vicinity of Winchester Creek, two miles southwest of Brasstown Church. Southwest of Winchester Creek only kyanite occurs in the schist zone. Between Winchester Creek and Brasstown Creek sillimanite is present in minor quantities. Northeast from Brasstown Creek the sillimanite increases in importance as a mineral constituent of the quartz-muscovite schist, being present in from three to five fairly distinct zones, each about 200 feet thick, over a belt width of about 2,000 feet. The sillimanite in the northwest portion of the belt is of the fibrous type, and is evenly distributed throughout the schist. The southeastern-most zone, which includes most of the Brasstown Church grounds, is intimately associated with pegmatites and contains additional sillimanite in the form of bladed aggregates. Teague and Furcron report a single sample from the locality as containing 4 percent sillimanite.<sup>2</sup>

Northeastwardly across the state line into North Carolina, exposures of sillimanite are scarce for nearly one mile, but appear once more on the slopes and brow of Davy Mountain. Considerable float sillimanite oc-



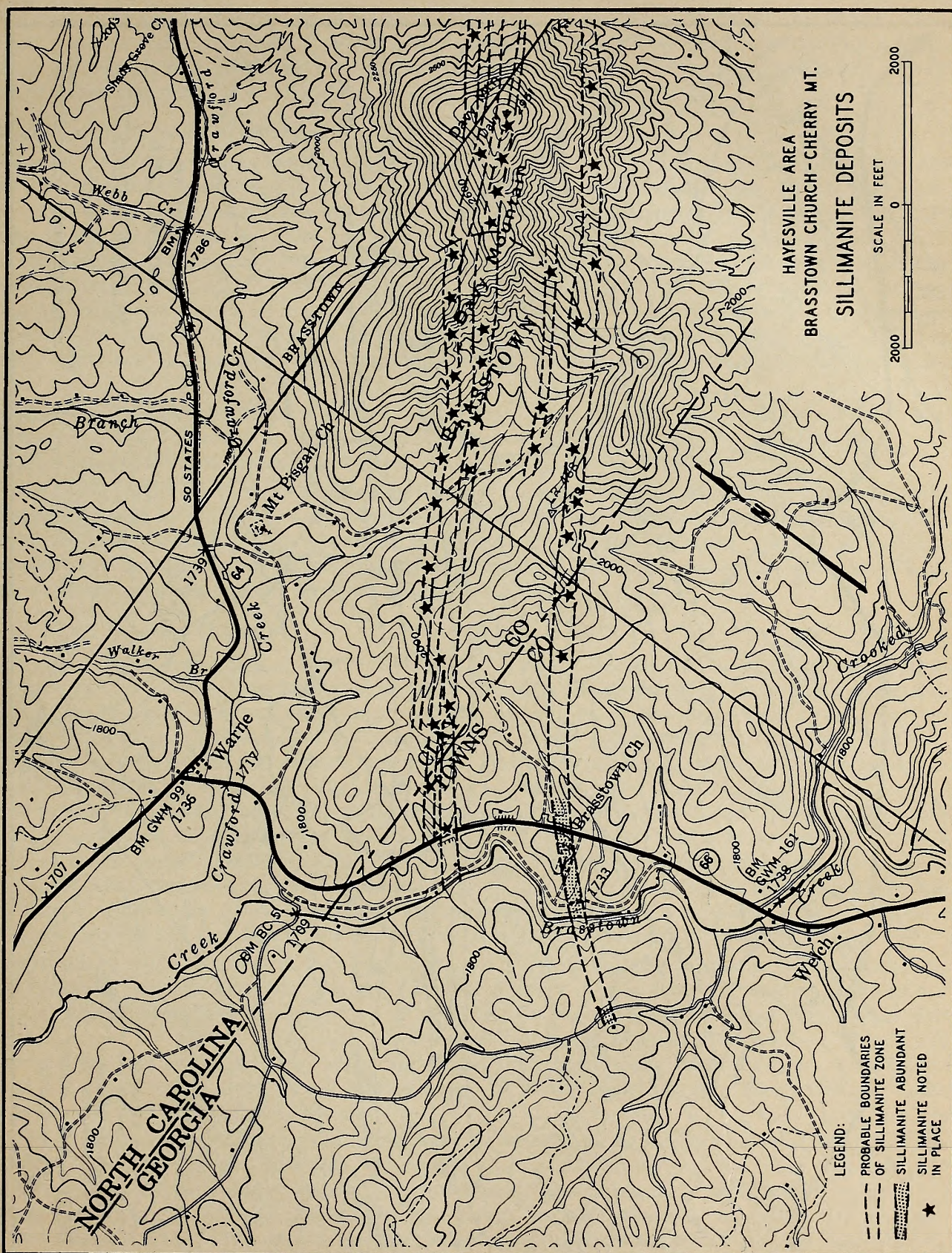
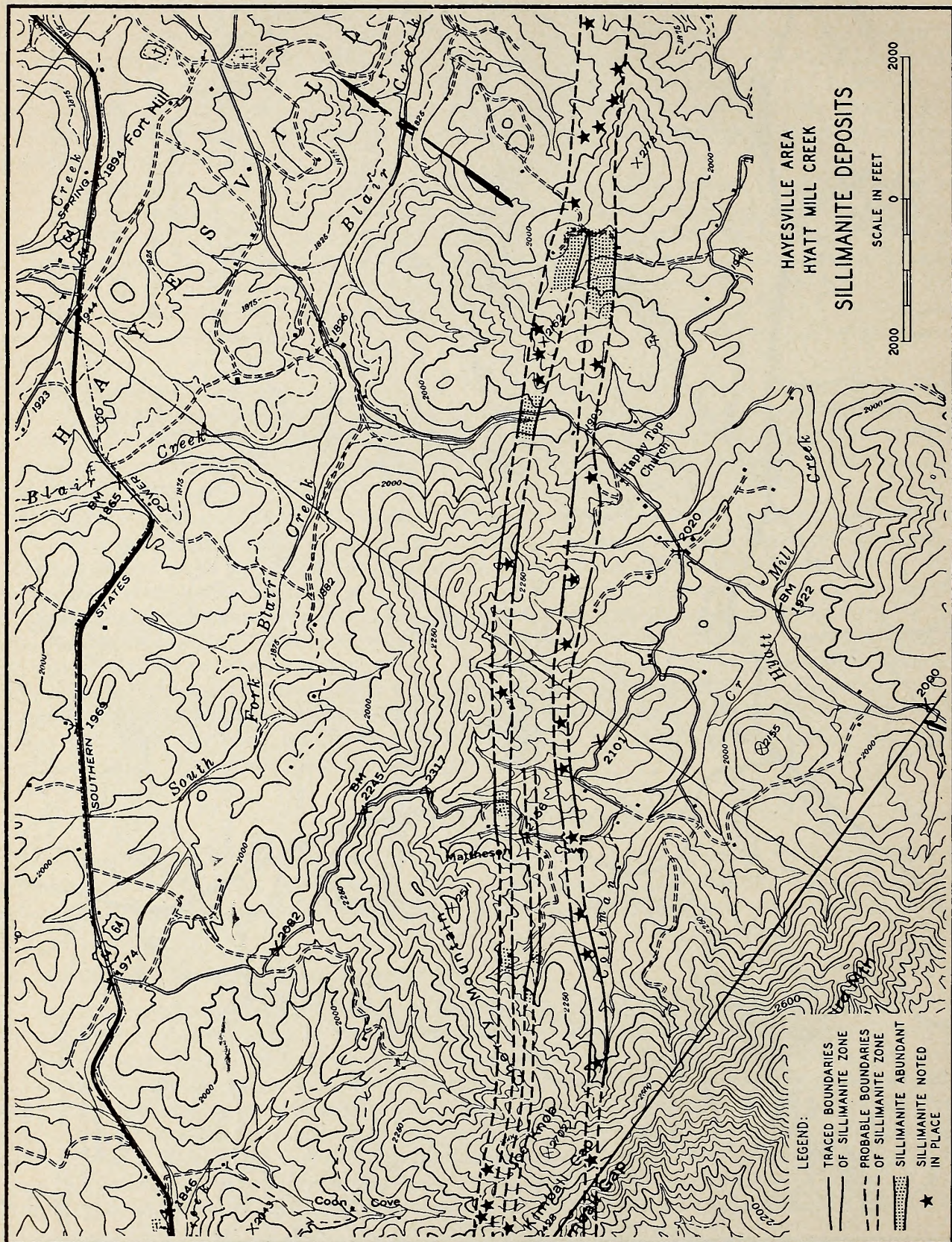


PLATE 7







curs but rock in place is not sufficient to warrant sampling. From Davy Mountain to Cherry Mountain, three and one-half miles southwest of Hayesville, zones of quartz-muscovite schist contain minor quantities of fibrous sillimanite, and bladed aggregates are represented by float, but the deposits are not attractive as sources of sillimanite ore.

#### Hyatt Mill Creek Deposits (Plate 8)

Between Cherry Mountain and the mouth of Hyatt Mill Creek, the sillimanite belt follows the northern portion of Hyatt Mill Creek-Coleman Creek drainage along the divide separating Hyatt Mill and Blair Creeks. Individual sillimanite zones are less definite and the belt narrows generally to less than 1,000 feet. Outcrops of sillimanite-bearing schist are found only at wide intervals, but float material indicates continuity of the deposits. One of the better exposures is on a knoll near an abandoned house on a small tributary of Coleman Creek, 2,400 feet N 78° W of the mouth of Mattheson Cove. A zone of about 30 feet in width contains prismatic and fibrous sillimanite, with minor quantities of bladed aggregates, in quartz muscovite-biotite schist inter-laminated with thin bands of pegmatite. A representative chip sample (Laboratory No. 606) contained 12.6 percent sinks, approximately 50 percent of the sillimanite showing sericite inclusions.

Sillimanite schist crops out for a width of about 100 feet in the bank of a county road 500 feet east of Mattheson Cove, but alteration to sericite seems to have been great and only 4.3 percent sillimanite was reported from a sample taken in 1942 by Messrs. Calver and McDaniel.

About 3,300 feet N 50° E from Happy Top Church, 1.7 miles south of Hayesville, blades of sillimanite are prominent along an unimproved road and in an open pasture. Occasional narrow outcrops of quartz-muscovite schist and pegmatite were sampled by Messrs. Calver and McDaniel, and found to contain 4.2 percent to 6.0 percent sillimanite. Similar results were obtained from material of the same type, 3,300 feet farther northeast, near the mouth of Hyatt Mill Creek.

#### Downing Creek Deposits (Plate 9)

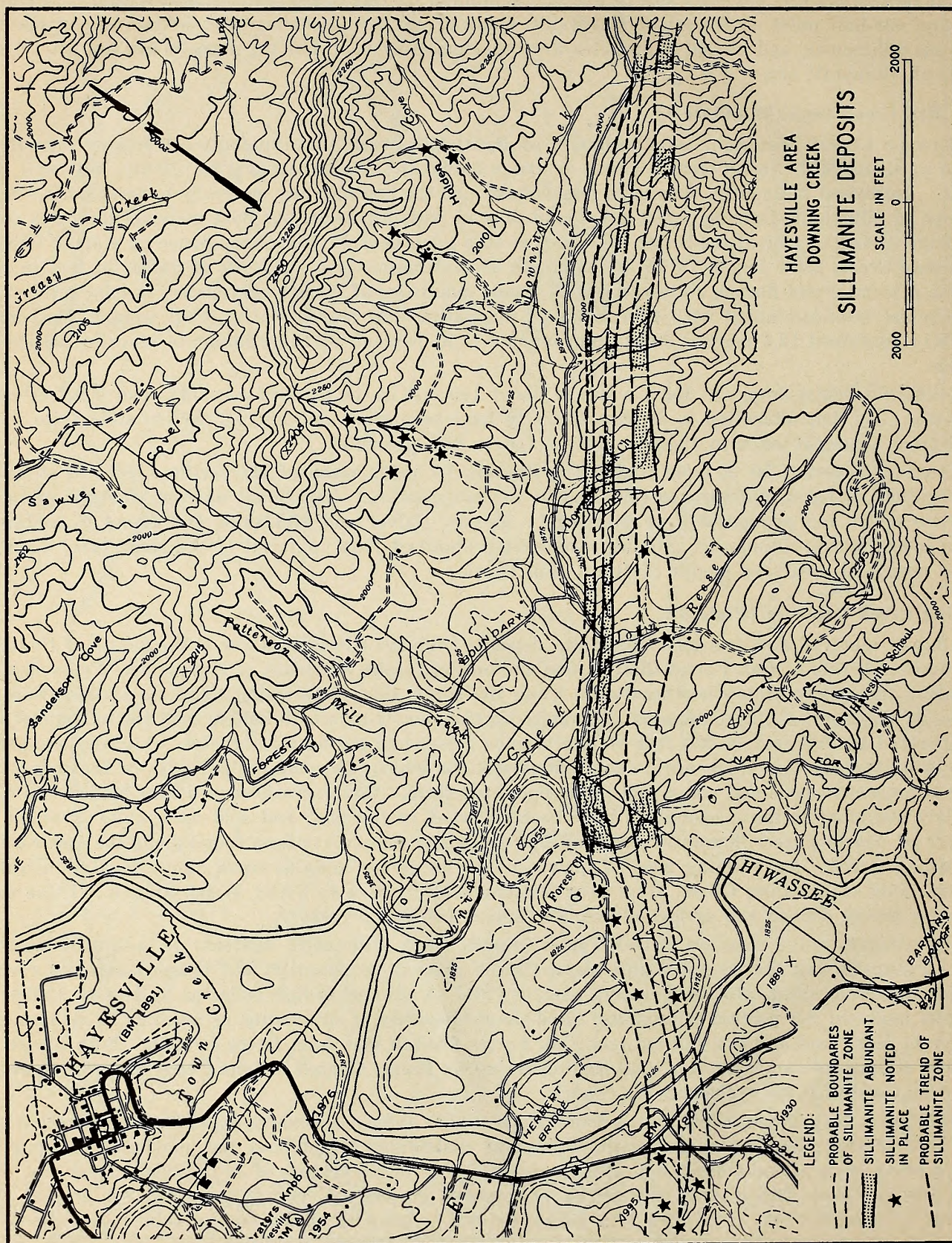
Alluvial material conceals any sillimanite deposits from the Hiwassee River at the mouth of Hyatt Mill Creek to the vicinity of Oak Forest Church, one and one-half miles southeast of Hayesville. From Oak Forest Church the belt continues northeastward along the south side of Downing Creek to its headwaters, a distance of three miles. Two zones of sillimanite-bearing quartz-muscovite schist, each 100 to 300 feet wide, are separated by 200 feet to 400 feet of quartz-mica gneiss and garnet-mica gneiss. Outcrops are present at frequent intervals, but there are no continuous sections which show the entire width of the zones. Pegmatite is present in pods and veins, and in disseminated form. Concentrations of coarse-bladed sillimanite are fairly abundant in talus, enough to have been collected in the past and sold as kyanite in small lots. Boulders of nearly pure sillimanite, weighing 300 pounds or more, have been found along the upper terrace of Downing Creek. An outlying zone of quartz-muscovite gneiss contains small amounts of sillimanite on the north side of Downing Creek, from near Patterson Mill Creek to Pecky Wood Branch. These occurrences are poorly defined and of low sillimanite content (up to 3 percent).

The cemetery and a road cut at Oak Forest Church show sillimanite contents in a quartz-muscovite schist. Prismatic and fibrous sillimanite appear to be present in quantity, but channel samples revealed less than 6 percent sillimanite (Laboratory sample 673). A channel sample collected by Messrs. Calver and McDaniel analyzed 9.9 percent sillimanite. Pod-shaped boulders of sillimanite, as much as 12 inches across, are present along and across a hill between Oak Forest Church and John Reece Branch. Both bladed and prismatic sillimanite occurs along a road leading from Oak Forest Church to John Reece Branch. Quality of the material is similar to that nearer the church.

Sillimanite float is noticeable across-country, as well as along a secondary road from John Reece Branch to the head of Downing Creek. Prismatic sillimanite, distributed throughout the quartz-muscovite schist, outcrops along branches and side roads which cross the belt. In the pasture of A. D. Sellers, 2,400 feet N 75° E of Downing Creek Church, two channel samples across 20 feet of section contained 8.4 percent sinks (Laboratory sample 675). The rock is a garnetic quartz-muscovite schist having thin pegmatite layers. A sample 1,400 feet east of the mouth of Bob Prater Branch contained 6.2 percent sinks (Laboratory sample 604). Other samples from this area studied include 605 and 607.



## SILLIMANITE DEPOSITS OF NORTH CAROLINA





In spite of the seeming abundance of coarse bladed sillimanite float in the Downing Creek vicinity, it is thought unlikely that coarse sillimanite can be found in sufficient quantity to be of important commercial value. An exception would be for the owners to collect sillimanite nodules and boulders in small lots for sale to a broker. Apparently the coarse sillimanite has been supplied by many small, scattered pegmatite pods and stringers and concentrated slightly in surficial deposits.

#### **Sap Sucker-Cold Branch Deposits**

Northeast from the head of Downing Creek, the sillimanite belt crosses a small divide into Tusquitee Creek drainage. Lean sillimanite-bearing schist occurs in a road cut at the first crossing of Sap Sucker Branch. A better sillimanite exposure is present in a road cut 600 feet southeast of the mouth of Pecky Wood Branch, where about forty feet of schist contains visible sillimanite. The rock is slightly graphitic and contains thin quartzitic beds and small pegmatite stringers. A channel sample (Laboratory sample 674) of the section contained 7.6 percent sinks.

A 20-foot zone of pegmatized schist, containing disseminated fibrous sillimanite, crops out 3,000 feet north of the mouth of Pecky Wood Branch. This occurrence could not be traced along the strike. One thousand feet south of this location, Messrs. Calver and McDaniel sampled a 40-foot outcrop of mica schist which was estimated to contain 2.5 percent sillimanite.

Northeast of Sunday Branch, and 6,000 feet above its mouth, four narrow zones of sillimanite-bearing schist occur over a cross-strike distance of 1,000 feet. Kyanite predominates over sillimanite in most of the exposures, but Messrs. Calver and McDaniel sampled one 20-foot garnetic zone which contained 7 percent sillimanite.

Minor amounts of sillimanite occur with kyanite in graphitic and garnetic schists on Cold Branch, but these deposits have no commercial value. From Cold Branch to the head of Tusquitee Creek, only a few exposures of the schist are present and these are devoid of visible sillimanite.

#### **Tusquitee Gap-Jarrett Creek Deposits**

Beginning at the Tusquitee Gap road, one-half mile north of the mouth of Bluff Branch, a lean sillimanite zone has been traced into Nantahala River drainage, crossing the divide about 200 yards east of Tusquitee Gap. The schist contains much sericite and small amounts of kyanite and graphite. From a point about one-half mile north of the divide, outcrops of the schist were not found, but float sillimanite occurs on either side of a projection of the belt. Sillimanite appears in four thin zones on the Aquone-Rainbow Springs Road northeast of the Horseshoe of Nantahala River. At a sharp bend in the road, on a southwest extension of the Jarrett Knob ridge, a 30-foot zone of intensely pegmatized mica schist contains about 5 percent fibrous sillimanite and minor amounts of the coarse-bladed sillimanite. Three additional zones of fine-grained muscovite schist occur for a distance of about one and one-quarter miles to the northeast, but they are too thin and too lean to be of value.

On the Rainbow Springs road, 2,000 feet west from Jarrett Creek, a zone of muscovite schist 150 feet thick, dipping 70° NW, contains prismatic sillimanite disseminated throughout the rock and coarse bladed sillimanite in association with pegmatite veins. A channel sample, taken across the entire 159-foot exposure, contained 8.0 percent sinks (Laboratory sample 687). The location would be ideal as a mine site for combination open cut and quarry-face work into a steep hill to the southwest. Adequate dump area is available in the steep drop to Jarrett Creek. Probably 150,000 cubic yards of sillimanite schist would be available initially, with a possibility of extension in to the mountain to the southwest.

This same sillimanite zone reappears 1,000 feet to the northeast in a bank of the Wayah Gap road on the north side of Jarrett Creek. The zone is less than 100 feet thick and possibly has a lower sillimanite content.

On the Wayah Gap-Aquone road, 1,000 feet east of its junction with the Rainbow Springs road, a rather lean sillimanite schist is repeated several times by lateral folds. The zone apparently is an extension of the one previously described as being on the Jarrett Knob ridge. Additional exposures to the northeast were not found.



### Burningtown Deposits

Except for a few small pieces of float 1,500 feet southeast of Jarrett Bald, sillimanite has not been found between the Aquone-Wayah Gap road and Whiteoak Creek, a distance of nearly four miles. Along the north fork of White Oak Creek, west of Licklog Gap, fibrous-massive sillimanite occurs as thick coatings on pegmatite quartz stringers, and as veinlets in quartz-muscovite schist. Similar forms of sillimanite occur at intervals from the head of Gold Pit Branch to about 1,500 feet east of Burningtown Gap.

An apparent extension of the White Oak Creek occurrence crosses an abandoned road 4,000 feet east of Burningtown Gap. Here fibrous and prismatic sillimanite is distributed in a 60-foot zone of a coarse-grained series of alternating muscovite schist and quartz-biotite gneiss. Blades of coarse sillimanite have been found in the creek bed but no concentrations were observed.

Prismatic sillimanite is found in a series of biotite schist zones, about 10 feet thick, on small tributary branches of Younce Creek, three miles northeast of the head of Burningtown Creek, and large blades of sillimanite occur in float of biotite gneiss about 2,000 feet east of Rattlesnake Knob at the head of Younce Creek. It is doubtful that any of these occurrences have commercial value.

From Younce Creek the sillimanite belt widens to include a cross-strike distance of nearly two miles. It is possible that some of the widening may be due to repetition by folding, but additional field data are needed in order to evaluate fully the geologic structure. Sillimanite float and occasional outcrops of sillimanite-bearing muscovite-biotite schist occur on Edwards Branch, Kelly Cove (Laboratory sample 740), and Kelly Ridge (Plate 10).

### Saldeer Deposits (Plate 10)

Saldeer Gap is situated 2.0 miles S 23° W from Etna Post Office. The main ridge cut by the gap trends south toward Horton Knob and north to Raby Bend of the Little Tennessee River. A prominent spur ridge trends westward to the Burningtown Creek road. Rock outcrops are scarce except in road cuts and in places where more quartzose rocks occur. Narrow and lean sillimanite zones occur along the Burningtown Creek road at 1,500 feet and 2,500 feet north of the mouth of Allen Branch, at the mouth of Kelly Cove Branch, at 1,400 feet northeast of the mouth of Kelly Cove Branch, and at 2,500 feet southeast of the mouth of Shope Cove Branch. These are occurrences of finely prismatic sillimanite disseminated in quartz-sericite schist. Concentrations are not of sufficient volume and grade to be considered as sources of sillimanite ore.

A sillimanite zone, nearly 1,000 feet wide, crops out on the Burningtown Creek road and on the point of the spur ridge leading west from Saldeer Gap. The northwest side of the zone crosses the Burningtown Creek road 900 feet southeast of the mouth of Kelly Cove Branch. The sillimanite, principally of the prismatic variety with minor quantities of fibrous and bladed varieties, is contained in a quartz-muscovite-biotite-garnet schist. Outcrops of the rock are not apparent to the southwest of Burningtown Creek, nor to the northeast of the spur ridge. A channel sample from a 40-foot outcrop near the southeast side of the zone contained approximately eight percent sillimanite (Laboratory sample 709), and a representative chip sample from the northwest side of the zone was estimated to contain 10 percent sillimanite (Laboratory sample 710). From 15 to 20 percent of the sillimanite crystals have sericite inclusions. Zircon and garnet composed about 10 percent of heavy mineral concentrates from the samples. Well over a million yards of sillimanite-bearing rock would be available at the locality above road level in the event that the ore is found to be desirable.

A smaller but richer sillimanite zone occurs on top of the ridge 1,200 feet north of Saldeer Gap, where prismatic sillimanite is disseminated in coarse-grained, pegmatized quartz-muscovite-biotite schist, exposed intermittently for a little more than 1,200 feet along a trend of N 60° E. The zone is 30 feet to 40 feet wide and dips 60° NW. Two similar chip samples from across the entire width of the sillimanite zone contained an average of 15.3 percent sillimanite, of which more than half had sericite inclusions (Laboratory sample 691). Approximately 50,000 cubic yards of ore would be available initially. The location of the deposit on top of a fairly sharp ridge and a spur would promote efficient mining by open cut methods. An unimproved road crosses Saldeer Gap, 1,200 feet away, but new access would have to be made to the deposit. Water supply in any large quantity is one-half mile from the deposit and 500 feet lower in elevation.







Sillimanite in garnet-quartz-muscovite schist is exposed irregularly as small outcrops and as float along the ridge north from Saldeer Gap to Long Branch, thence along a spur ridge leading northeast toward Oak Grove. Other exposures occur along a line from the point of Raby Bend southwest to the Burningtown road and northeast to the Little Tennessee River at Etna, and at locations 700 feet west of the mouth of Rose Creek and 2,000 feet SSW of the McCoy Bridge. None of these exposures are sufficiently rich for testing.

#### **Oak Grove Deposit (Plate 11)**

Sillimanite occurs in a 300-foot zone on the north side of U. S. No. 64 at Oak Grove Cemetery, 2,000 feet northwest of Etna Post Office. The rock has been weathered extensively, but appears to be a garnet-mica schist. Small radiating bundles of prismatic sillimanite are well distributed throughout the exposure and a few small blades of coarse sillimanite were found in a thin vertical pegmatite vein on the southeast side of the zone. A chip sample collected from this outcrop contained an estimated 7.6 percent sinks (Laboratory sample 698-C), all of which showed numerous sericite inclusions (See also sample 799). Indications of an extension of the zone along the strike to the northeast or southwest are lacking, principally because of concealing talus and alluvium.

#### **Etna-Bradley Creek Deposits (Plate 11)**

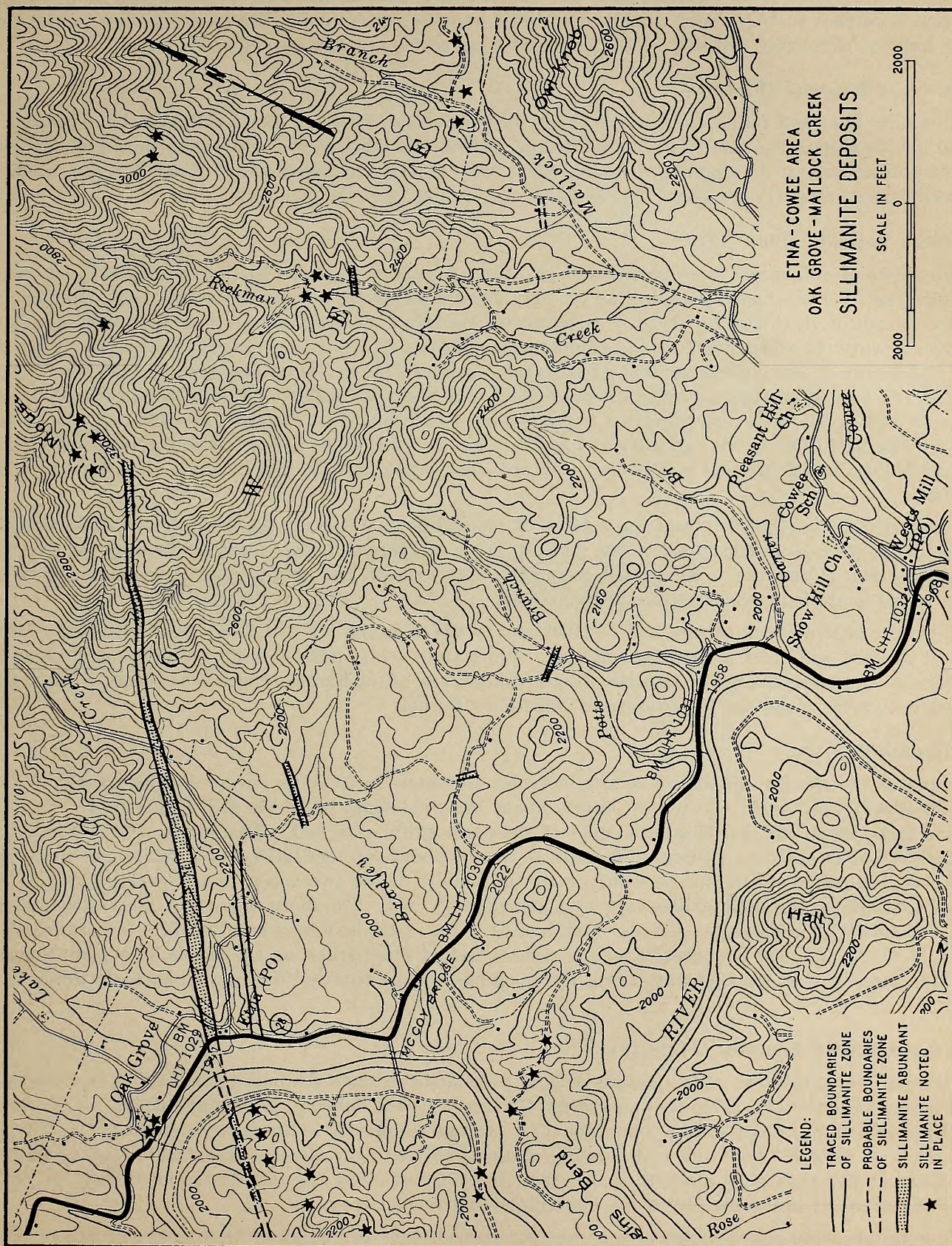
A probable extension of the Raby Bend sillimanite zone has been traced almost continuously northeastwardly from U. S. No. 64 at Etna Post Office to the southernmost gap of Mouse Mountain, a total distance of 8,000 feet. The rock is quartz-muscovite-biotite-garnet schist, ranging in thickness from 50 feet to nearly 400 feet. The northeastern half of the exposed zone, from Bradley Creek to Mouse Mountain, appears to be narrower and to contain less sillimanite than the southwestern half from Bradley Creek to the highway. Sillimanite is present both as individual prisms and as radiating aggregates of prisms. The richer sillimanite is associated with pegmatization. Five channel samples, each representing 45 feet to 65 feet of rock, were taken where the zone crosses the Bradley Creek road near the old Bradley place. Sillimanite content of the samples ranged from 7 percent to 13.5 percent, and averaged 9.7 percent for the entire width (Laboratory samples 698-A, B, D, E, and 741). Associated heavy minerals include zircon, garnet, ilmenite, and limonite; 50 percent of the sillimanite contained sericite inclusions. Rock outcrops along the secondary road between Etna and Oak Grove appear to be as rich in sillimanite as those at Bradley Creek. A probable minimum of one-half million cubic yards of ore, averaging 10 percent sillimanite, is available between Etna and Bradley Creek. Topographic conditions along the zone are favorable for open cut mining. Access, water supply, electric power, and dumping facilities are excellent. A chip sample from the top of Mouse Mountain contained 10.1 percent sillimanite (Laboratory sample 701), but the zone between Bradley Creek and Mouse Mountain would have to be prospected by trenching or boring before volume and grade of the sillimanite could be estimated.

Much of the Etna-Bradley Creek locality is overlain by alluvial material which conceals possible sillimanite deposits. Indications of sillimanite have been found, however, in the following places: On U. S. No. 64 at 500 feet and 900 feet southeast of Etna Post Office, and on secondary roads at 2,400 feet N 70° E of Etna, at 4,200 feet N 43° E of McCoy Bridge, and at 3,400 feet N 30° W and 2,500 feet N 5° E of the mouth of Potts Branch. A chip sample from the latter location, representing 15 feet of rock contained 16.1 percent sillimanite (Laboratory sample 690), indicating the desirability of additional prospecting.

#### **Rickman Creek Deposits (Plate 11)**

Rickman Creek is the western tributary of Matlock Creek, which joins with Cowee Creek one and one-half miles northeast of Wests Mill Post Office. Three sillimanite horizons occur within a cross-strike distance of 700 feet along the Rickman Creek road, 5,000 feet north of Matlock Creek. None of the horizons could be traced for more than a few hundred feet along the strike. The two northernmost zones are lean in sillimanite but the lower zone is more encouraging. The latter is 65 feet in width and is composed of a quartz-muscovite-biotite schist which strikes N 65° E, dipping nearly vertical. Sillimanite occurs in the schist as disseminated prismatic and fibrous forms, also as the radiating bundles. Two channel samples were taken, one representing 35 feet of rock (southeast side) contained 5.7 percent sillimanite, and one representing an





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additional 30 feet section contained 2.6 percent sillimanite (Laboratory samples 688-A and B). In addition, from 5 percent to 10 percent combined kyanite, limonite, ilmenite, and zircon are present in the heavy mineral faction. Probably one-half of the sillimanite has sericite inclusions. (Also see sample 702.)

#### **Matlock Creek Deposits (Plate 11)**

Sillimanite has been found on Matlock Creek above Rickman Creek at four localities. All exposures are thin and low in sillimanite, and could not be traced beyond the discovery outcrops. One sample, taken across 15 feet of rock at an abandoned house, 4,500 feet northeast of the mouth of Wests Branch, contained 9.7 percent sillimanite (Laboratory sample 700), all high in sericite inclusions.

#### **Leatherman Deposits (Plate 12)**

Indications of sillimanite have been found at widely scattered locations in the vicinity of Leatherman, three miles east of Etna Post Office, but as yet only one zone appears worthy of prospecting. Immediately below the mouth of Huckleberry Creek, a tributary of Beasley Creek, sillimanite occurs in quartz-muscovite schist over a width of about 500 feet. A sample across 50 feet of a particularly rich horizon contained 19.5 percent sillimanite of low sericite content (Laboratory sample 711). Visual comparison indicated that an additional 100 feet of section may contain more than 8 percent sillimanite. Mining would not be feasible to the northeast of the discovery exposure, but favorable conditions exist toward the southwest where elevations rise from 3,000 feet at the exposure to 3,300 feet on Cedar Cliff Ridge, a horizontal distance of 2,000 feet. Fresh rock is not exposed in the area, but firm rock probably would be encountered within 30 feet of the surface.

A zone of kyanite schist containing masses of pegmatite-type kyanite has been found from Mill Gap, 3,000 feet northwest of Leatherman, to the western slope of Panther Ridge, north of Beasley School. Prismatic and fibrous sillimanite is associated intimately with kyanite, but separation of a pure sillimanite concentrate would be difficult (See samples 689 and 746.)

Sillimanite-bearing rock occurs east of Huckleberry Creek to the top of Cowee Mountains, but quantity and grade are not sufficient to justify sampling. Sillimanite schist float is scattered between Beasley and Blazed Creeks and along the top of Panther Ridge. Sillimanite of the fibrous type also has been found in feldspathic garnet gneiss along the headwaters of Mica City Branch.

#### **Cowee Church Deposits**

Prismatic and fibrous sillimanite occurs in schist inclusion in granite gneiss on the western end of Mason Mountain, just south of Cowee Church, about one mile south of Wests Mill Post Office. These deposits are just outside the southeastern limits of the main sillimanite belt. Two zones, 700 feet and 1500 feet south of Cowee Church, contain sillimanite in a zone about 150 feet thick. Concentrations of sillimanite, however, are restricted to 60-foot widths near the centers of the two zones (See samples 738 and 739). Principal foliation of the rock strikes east-west and dips 85° SE. The more important associated minerals are quartz, feldspar, sillimanite, sericite, and biotite. The rock is weathered but firm in exposures on highway U. S. No. 64, but is concealed under several feet of overburden on the slopes of Mason Mountain and in open land west of the highway. Prospect openings will be required in order to evaluate properly the deposits.

#### **Greens Creek School Deposits (Plate 13)**

A zone of about 150 feet of sillimanite-bearing migmatite extends for more than 1,000 feet northeast of the Peewee Branch road, 2,500 feet northwest of Greens Creek School. A channel sample of 25 feet of the best exposed part of the section contained 17.4 percent sillimanite (Laboratory sample 737). The rock strikes N 55° E, dips 80° NW, and makes angle of about 45° with the Greens Creek road (See also sample 751). Ground elevation rises more than 300 feet in 1,400 feet along the zone to the northeast. A projection to the southwest lies generally in the bottomland of Greens Creek.

Sillimanite-bearing schist appears in a road cut immediately northeast of Greens Creek School at the intersection of the Brushy Fork road. The zone is exposed at intervals for 2,000 feet northeast to its inter-



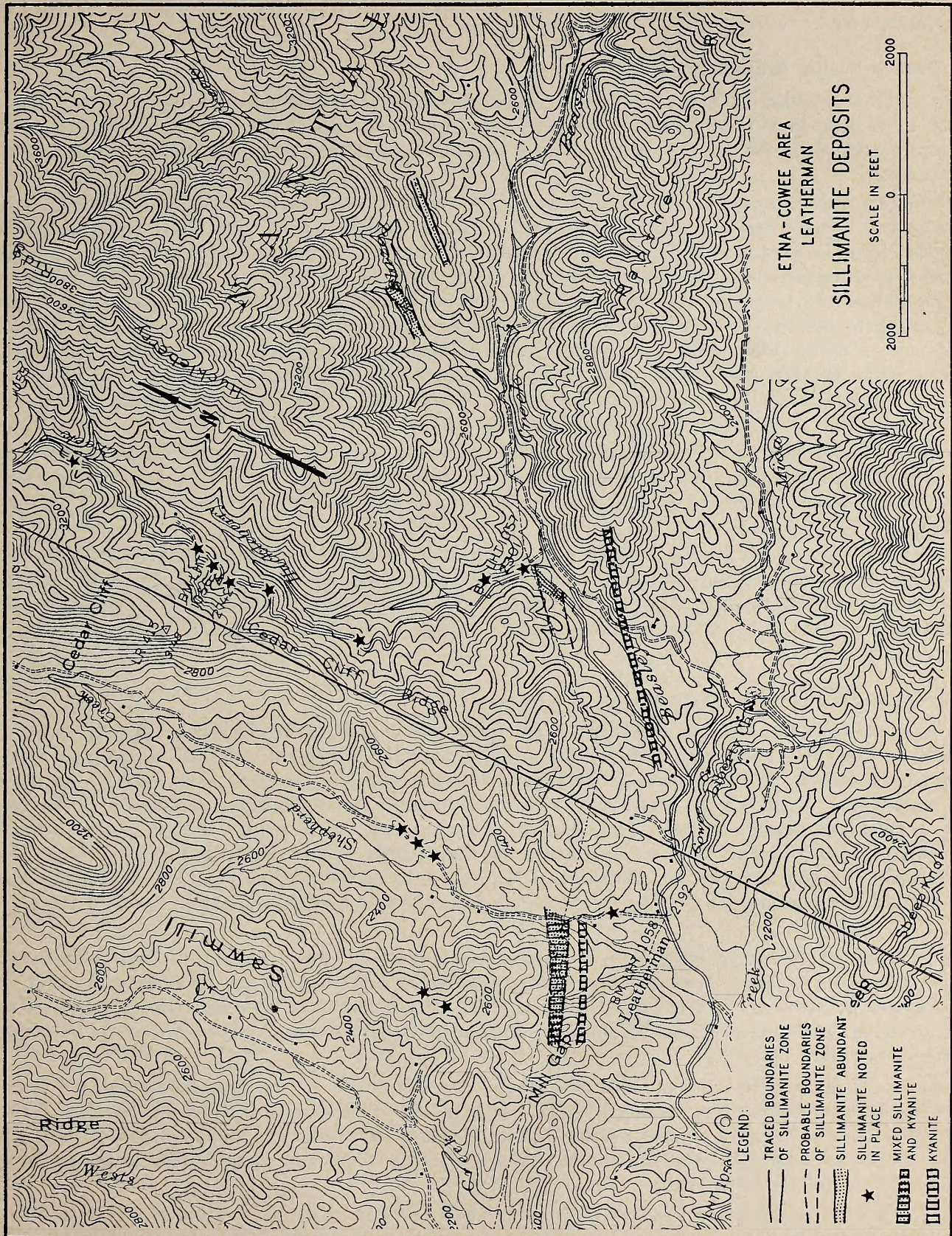


PLATE 12



section with the electric transmission line, and a continuation farther northeast is possible, but an evaluation is unsatisfactory without prospect openings.

#### **Brook Branch-Sutton Branch Deposits (Plate 13)**

The sillimanite zone exposed at Peewee Branch continues on and between Brook and Sutton Branches at about 4,000 feet above their mouths. Sillimanite is associated with biotite in a quartz-muscovite schist of moderate pegmatite content. Approximately 8 percent sillimanite is present in the rock over a width of about 20 feet.

Sillimanite occurs on the Brook Branch road 2,200 feet above its mouth, but extension along the strike was not found. At 800 feet and 400 feet above the mouth of Brook Branch, sillimanite zones of about 25-foot widths occur in road cuts and have been traced intermittently for several thousand feet along the strike. Exposures of sillimanite-bearing rock are not sufficient, however, to estimate economic value. A more promising sillimanite zone, probably an extension of the occurrence on Brushy Fork, extends along Greens Creek, across the mouth of Brook Branch, to 350 feet above the mouth of Sutton Branch. The sillimanite-bearing portion of the feldspathic quartz-muscovite schist ranges in thickness from 10 feet to 60 feet. Local dips range from 65° NW to vertical. The richer portion of the zone is about 1800 feet of strike length southwest from Sutton Branch. A sample from the Sutton Branch end of the zone, representing 60 feet of section, contained 20.0 percent sinks (Laboratory sample 752).

A rather lean zone of sillimanite-bearing schist, up to 200 feet wide, extends from 2,200 feet above the mouth of Sutton Branch northeast to Cagle Branch. A 15-foot portion of the section was the only part of the zone which seemed worthy of sampling, but prospect openings along the strike might reveal more promising data.

Sillimanite occurrences are poor between Cagles Branch and the Tuckasegee River. Probable extensions of the Peewee Branch-Sutton Branch zone and the Sutton Branch-Cagle Branch zone have been traced to the northeast with difficulty. Almost continuous rock exposures across the sillimanite belt are present in southwest road cuts of U. S. No. 64 along Tuckasegee River, but sillimanite of economic concentration is not present.

#### **Riverview Church Deposits (Plate 14)**

A southwest-trending spur of Kings Mountain forms steep bluffs over the Tuckasegee River at from 1,000 feet to 2,000 feet northwest of Riverview Church, 1.6 miles southwest of Sylva. Ledge rock is nearly continuous across the 1,000 foot width of the spur, all containing sillimanite to some extent. At approximately equal intervals across the bluff, four zones of sillimanite concentrations, ranging from 20 feet to 60 feet in thickness, were sampled. The sillimanite-bearing rock can be studied at this locality both along the strike and down the dip. Samples collected from this locality (Laboratory samples 717, 742-745) contained between 6.4 and 19.6 percent sillimanite. Mining of the deposits would be aided by their occurrence in steep bluffs, but operational troubles might result from the fact that dips in the rock vary from 65° NW to 70° SE.

Intermittent exposures of sillimanite rock have been observed northeastward to the crest of Kings Mountain (See sample 712). Most of the ground is covered by talus, but it seems likely that firm rock would be encountered at less than 20 feet beneath the surface. If sillimanite of economic concentration is found to be continuous to the top of Kings Mountain, a comparatively unlimited supply of ore would be available.

#### **Sylva Deposits (Plate 14)**

Decomposed sillimanite-bearing schist is exposed in a cut at the end of a paved street 1,600 feet due south of the Jackson County Courthouse in Sylva. Locally the foliation dips 70° SE and strikes N 35° E. Intermittent outcrops indicate a zone width of about 100 feet but continuity along the strike could not be verified. Small outcrops and some sillimanite schist float occur 2,000 feet east of this location, but none seemed worthy of detailed prospecting.

A 30-foot zone of sillimanite-bearing feldspathic quartz-sericite schist, containing 11.3 percent sillimanite (Laboratory sample 736), crops out in a highway cut of U. S. No. 19-23, 450 feet north of its intersection with N. C. No. 107. The zone crosses a small spur ridge and into a small stream valley at the northeast



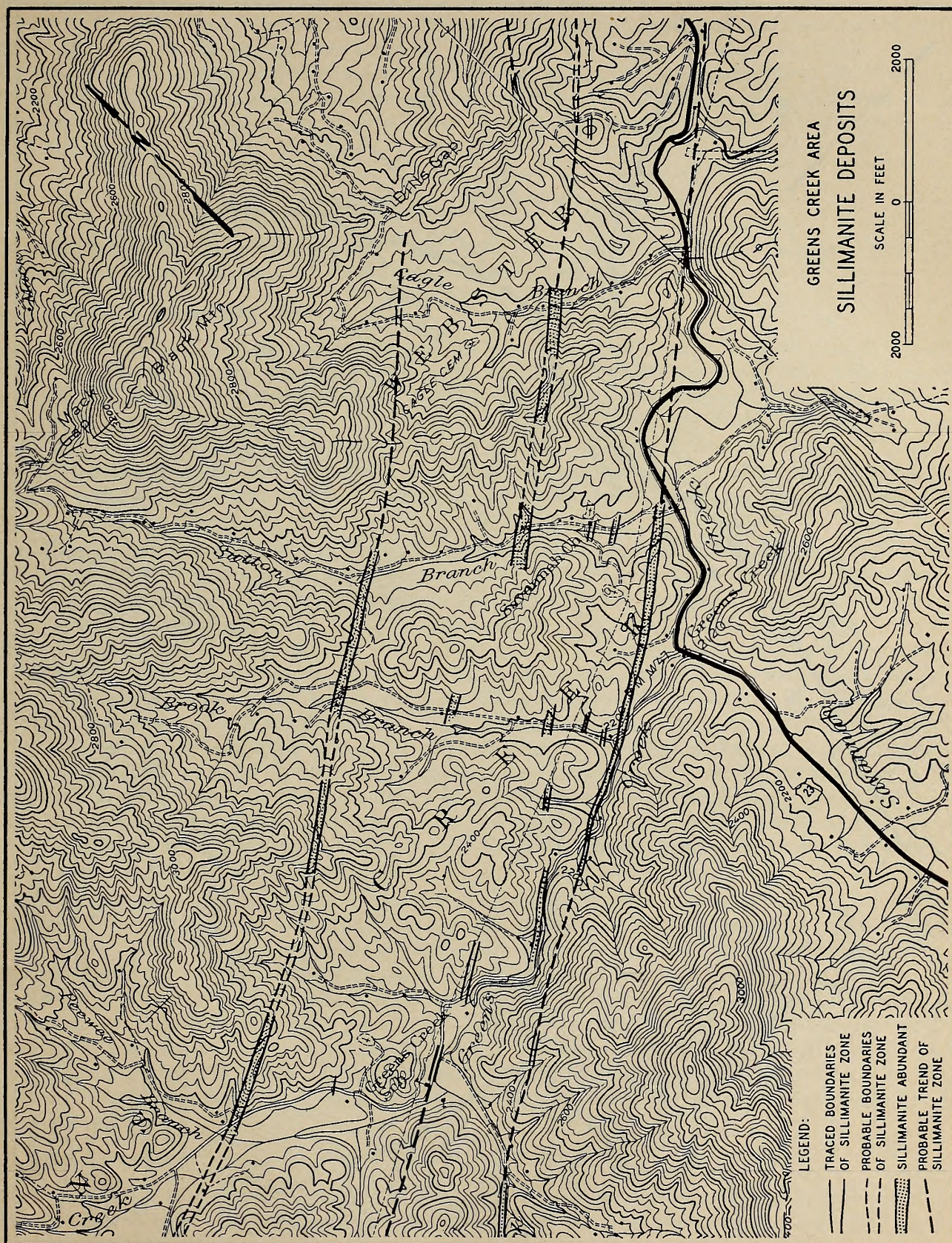
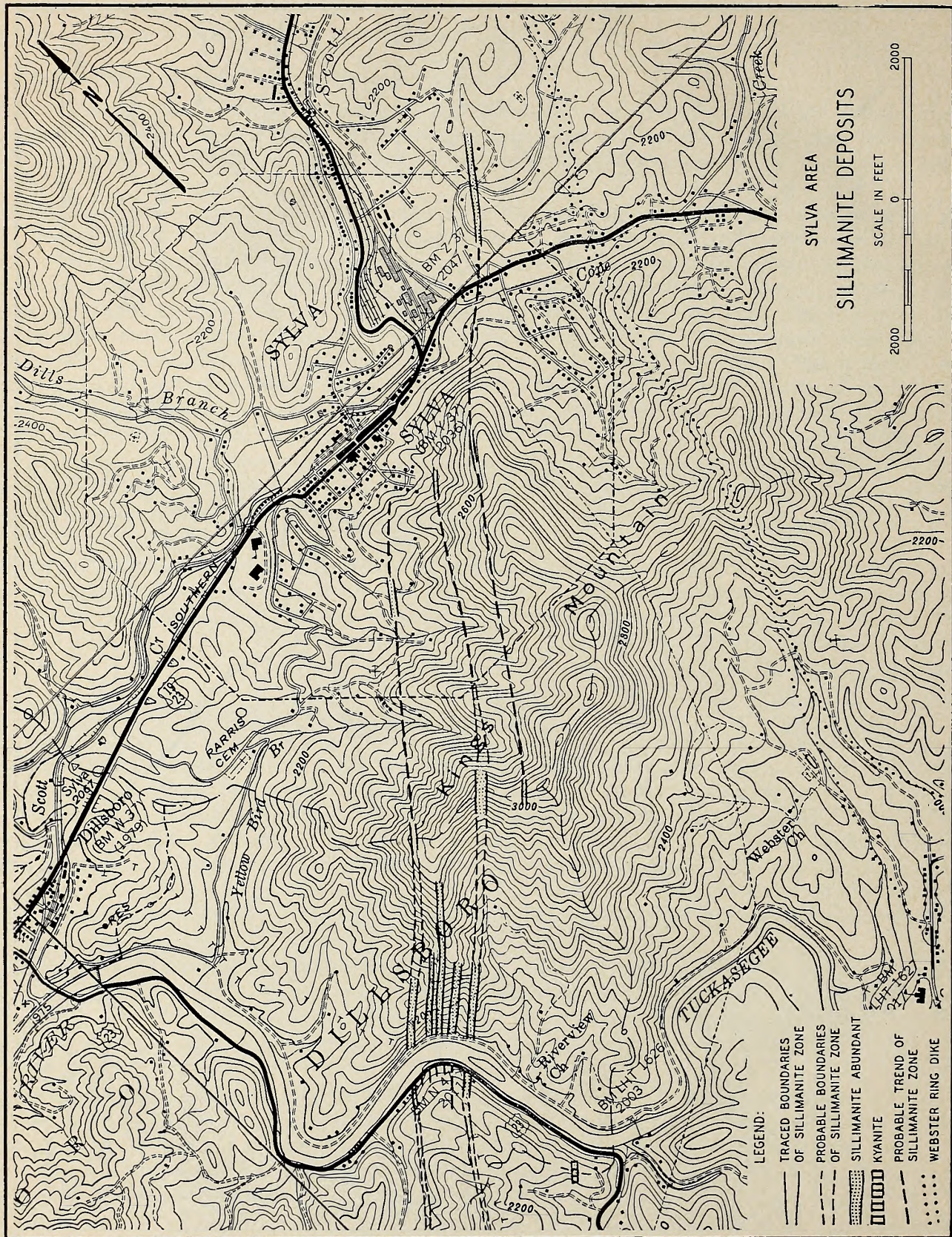


PLATE 13





USGS-TVA QUADRANGLES 175-NW, SW; 166-SE



corner of the Sylva city limits, a total outcrop distance of about 1,300 feet. Local strike and dip of the zone is N 30° E, 85° SE. Rocks immediately northwest of the sillimanite have the appearance of decomposed granite, probably representing a very strongly pegmatized mica schist. To the southeast of the zone the rocks apparently are thoroughly weathered biotite-garnet gneiss. Sillimanite in the zone is of both fibrous and prismatic form. Considerable alteration to sericite makes difficult any visual estimates of the sillimanite content. Any mining at the locality would be comparatively easy because of the steep dip and moderately high ground.

## OTHER SILLIMANITE DEPOSITS

In addition to the two principal zones of sillimanite-bearing rocks in North Carolina, other sillimanite occurrences are known and some of these occurrences are here described.

### Grassy Ridge-Big Ridge Deposits

Although a well-defined sillimanite belt has not been traced northeast of Sylva, two additional sillimanite localities have been found in a geologic setting different from that to the southwest. These localities are near the Grassy Ridge mica mine, 2.1 miles S 36° E of Balsam Gap, in Jackson County, and at the Big Ridge mica mine, 5.1 miles S 6° E of Waynesville, in Haywood County. The Big Ridge mine is four miles nearly due east of the Grassy Ridge mine. The geology of the two localities is similar. Large mica pegmatites occur in quartz-mica schist and gneiss and quartz-garnet-biotite gneiss. Smaller masses of pegmatite are present as pods, stringers, and laminae. Sillimanite is present in some of the quartz-garnet-biotite gneiss as fibrous bundles and laminae.

Sillimanite was first noted on the Grassy Ridge mine access road 2,000 feet southwest of the mine (Laboratory sample 656). Boulders of garnet-mica gneiss were found to contain appreciable sillimanite. A sample (No. 704) was analyzed and found to contain 20.6 percent heavy minerals, of which 70 percent was garnet, 25 percent was sillimanite, and 5 percent was combined rutile and ilmenite. Zircon, chromite, and barite were present in trace quantities. During the field program, studies at the locality were hindered by heavy foliage, so that exact data are limited. Apparently the sillimanite zone is rather thin and quite variable in sillimanite content. Local strikes range from north-south to east-west, but the trend over a distance of a mile or more seems to be about N 65° E. This was partially verified by the finding of small amounts of sillimanite where the mine road crosses a small gap 2,800 feet southeast of Beetree Gap. Scattered sillimanite float occurs all along the strike between the gap and the Grassy Ridge mine, but no outcrops of high sillimanite content were observed. The sillimanite in hand specimen is oriented along the major foliation of the quartz-biotite-garnet gneiss, usually in augen-like masses up to one inch long and one-fourth inch thick. Sillimanite appears to be present in large quantity, but microscopic examination shows considerable alteration to, or replacement by, sericite and quartz.

Sillimanite has not been observed between the Grassy Ridge mica mine and the Big Ridge mica mine, although chance of observation in that interval is poor because of a heavy foliage and limited outcrops. At the Big Ridge locality the geology is similar to that at Grassy Ridge. Rocks including the mica pegmatite are quartz-biotite-garnet gneiss which in places is quite schistose. Locally the rocks strike N 45° W to N 55° W, and dip 40° to 70° SW. Sillimanite is most prominent in a cut of the mine access road between the main adit opening and the principal surface openings of the mica mine. As at Grassy Ridge the sillimanite is principally of the fibrous variety, arranged in small augen-like masses along the schistosity. Pseudomorphs of quartz-sericite mixtures, after sillimanite, are quite noticeable even in hand specimens. Although samples have not been analyzed, it is doubtful that any of the rock thus far found has more than two or three percent sillimanite.

### South Hominy Deposit

Sillimanite has been found at one locality in the South Hominy section of Buncombe County, 2.8 miles north of Mount Pisgah. Strongly pegmatized quartz-garnet-biotite-muscovite gneiss and schist on the northern end of Ripshin Mountain contains sillimanite in fibrous, prismatic, and coarsely bladed forms. Local strikes range from N 65° E to N 80° W, and dips are from 65° SE to vertical. The sillimanitic zone appears



to be as much as 800 feet wide, as exposed on the crest of Ripshin Mountain and in test pits on property of Julius West on the west slope of the mountain. Some kyanite is visible in overburden, and all forms of sillimanite exhibit alteration to sericite and quartz. Exposures of the sillimanite rock are not sufficient to furnish representative samples, so that sillimanite content of the material has not been determined. Additional prospect openings will be required for a reasonable evaluation of the deposit. Field studies for several miles east and west of the locality have not revealed additional sillimanite.

#### **Asheville-Mount Mitchell Deposits**

Two zones of sillimanite-bearing rock are known to occur near Asheville, Buncombe County, North Carolina. Most of this area is in the Pisgah National Forest and is characterized by steep-sided mountains and high peaks, Mount Mitchell being the highest peak east of the Mississippi with an elevation of 6,684.

The zone containing the more promising sillimanite deposits occurs approximately 2 miles north of Asheville, striking roughly N 60° E. A small amount of geological work in the area indicates that the sillimanite-bearing rock occurs in discontinuous bands from a point southwest of Asheville to or beyond the Mount Mitchell area. Sillimanite was discovered on Mount Mitchell in the summer of 1949. Deposits of schist containing sillimanite occur also on the northwest side of Jump Cove, 4½ miles N 45° E of Asheville. At both of these localities the sillimanite occurs in a quartz-muscovite-biotite schist. Fine needle-like crystals and sillimanite nodules up to 2 inches in diameter are present. A representative chip sample of schist taken from the northwest side of Jump Cove contained 17.3 percent sinks in heavy liquid (Laboratory sample 770).

Sillimanite-bearing rock crosses the Asheville Recreation Park 3½ miles southeast of Asheville, striking roughly parallel to the zone described as occurring north of Asheville. All of the outcrops examined at this occurrence contain a low percentage of sillimanite and exhibit extensive alteration to sericite.

### **LABORATORY RESULTS**

The field samples collected during this survey were processed in the North Carolina Minerals Research Laboratory by Euan K. Greene, Student Assistant of the North Carolina Division of Mineral Resources, and Earl C. Van Horn.

#### **METHOD EMPLOYED FOR SAMPLE ANALYSES**

Since the quantity of sillimanite in sillimanite-bearing rock cannot be determined accurately by visual inspection, it was necessary to develop a quick and simple laboratory technique for analyzing the samples for their sillimanite content.

The following procedure was used to determine the sillimanite content of samples collected by field parties.

Sillimanite ore was crushed and screened at —100 mesh. A charge of 5 grams of the sized ore was placed in a 250 cc. beaker and enough concentrated hydrochloric acid added to cover the material. The mixture was diluted with an equal volume of tap water and placed on a water bath at 100° C. At intervals of 5-10 minutes, the mixture was diluted with additional water to a total of about 150 cc. volume and for a total leaching time of about 20 minutes.

The leached material was filtered and washed thoroughly with tap water and oven-dried for one hour at 105° C. A four-gram charge of leached ore was placed in a 15 cc. centrifuge tube and the volume brought to 12 cc. with Acetylene tetrabromide (specific gravity of 2.95). The mixture was shaken thoroughly to obtain good dispersion of the mineral grains. The charge tubes were then placed in a Clay-Adams Safety Head centrifuge, operated on an A.C. current and centrifuged three minutes at position 6 (about 3700 r.p.m.). Water was used in the metal tube holders to distribute pressure on the glass tubes.

The floats were removed by decantation and any middling grains which remained in suspension were poured off with the floats. The floats and sinks were re-centrifuged separately with acetylene tetrabromide to insure a thorough cleansing.



The heavy liquor was filtered from the floats for re-use. The floats and sinks were separately washed several times with previously used benzene and given two final washes with unused benzene. Washing was best accomplished in a beaker rather than on filter paper. Following the benzene wash the two products were washed several times with hot tap water. Filter bottles and fluted funnels were used for rapid filter washing. After drying for one hour at 105° C., the material was weighed and percentages calculated on the basis of the total weight before leaching. Sillimanite (specific gravity of 3.23) in its pure form sinks readily in the heavy liquid but sericite (specific gravity 2.6-3.1), an alteration product of sillimanite sometimes is carried down with the sinks. Partial alteration to sericite may also cause small quantities of sillimanite to appear in the floats. Any heavy minerals such as garnet, ilmenite, sphene, rutile, zircon, etc. also dilute the sinks.

The use of a petrographic microscope was necessary in order to apply percentage corrections required by dilution of the sinks by sericite and other heavy minerals and by carry-over of sillimanite to the floats. After the various fractions had been separated and dried, the individual sample fractions were mixed thoroughly on a cutting cloth and a small sample transferred to a glass slide where the fraction was mixed in a drop of immersion liquid, refractive index 1.65. Corrective factors were obtained where necessary by means of a microscopic grain count, except that grain counts were not necessary where the sillimanite fraction was quite pure.

In the event that sinks from acetylene tetrabromide contain too great a fraction of heavy minerals for rapid microscopic counts, the sinks may be separated further by use of methylene iodide (specific gravity 3.25). The procedure for using the methylene iodide is identical with that used with acetylene tetrabromide except that the sillimanite concentrates appear as floats.

#### ANALYSIS AND LOCATION OF SAMPLES FROM THE CLIFFSIDE-ELKIN SILLIMANITE BELT

<i>Laboratory Number</i>	<i>Percent Sinks</i>	<i>Percent Sillimanite</i>	<i>Location</i>
648-C*	11.6	11.1	Near Hollis, Rutherford County
648-D*	14.6	13.1	Road cut sample from Cages Mountain, Caldwell County
648-E*	13.8	4.1	Road cut at Fox's Orchard, Iredell County
648-H*	13.4	12.2	Surface float sample, Cages Mountain, Caldwell County
648-M*	12.0	10.8	Along Cedar Valley, Alexander County
660-1	6.4	}	Smith Cliff Deposit, Burke County
660-2	6.2		
660-3	4.4		
660-4	9.2		
660-5	5.8		
660-7	6.0		
660-8	11.0		
662-1	10.6	}	Fox's Orchard Deposit, eleven miles northeast of Taylorsville, Iredell County
662-2	11.2		
668-B*	14.8	11.4	}
668-C*	13.6	13.3	
668-D*	12.2	11.4	
668-E	8.2	13.6	
668-F*	14.2		
669-1	7.4		
669-2	9.6		
669-3*	10.6	9.7	Cages Mountain Deposit, Caldwell County
669-4	10.2	14.3	
669-5*	15.4		
669-6	5.0		
669-7	5.0		
669-8	6.8		
669-9	9.8		



<i>Laboratory Number</i>	<i>Percent Sinks</i>	<i>Percent Sillimanite</i>	<i>Location</i>
686	9.4		Sawmill Ridge, Caldwell County
694*	18.8	17.7	} Four miles south of Taylorsville, Alexander County
695*	11.6	11.0	
696-A*	14.0	12.7	} Highway No. 16 north side of Brush Mountain, Wilkes County.
696-B*	13.4	12.2	
707-A*	24.0	20.8	Dudley Shoals I Deposit, about 2 miles west of Dudley Shoals
707-B*	20.4	18.3	Dudley Shoals I Deposit, about 2 miles west of Dudley Shoals
707-C*	19.8	16.0	Dudley Shoals III Deposit, about 2 miles west of Dudley Shoals
707-D*	35.2	31.6	Dudley Shoals III Deposit, about 2 miles west of Dudley Shoals
708-A*	30.0	27.0	Dudley Shoals II Deposit, about 2 miles west of Dudley Shoals
708-B*	20.8	17.7	Dudley Shoals III Deposit, about 2 miles west of Dudley Shoals
713-1	0.2		} Near Hollis, Rutherford County
713-2*	33.2	29.0	
713-3	6.4		
713-4*	12.8	11.5	
713-5	1.6		
713-6	5.2		
713-7	5.0		
713-8*	24.8	22.3	
713-10*	16.0	15.2	
713-11*	16.4	13.9	
713-12	9.0		
713-13*	12.0	8.4	
713-14	7.6		
730	17.3	13.6	} Dudley Shoals I Deposit, about 1½ miles west of Dudley Shoals Caldwell County
731-A	9.3	4.8	
731-B	12.3	6.4	
732-A	12.0	4.3	
732-B	5.7	2.3	
732-C	9.3	5.1	
732-D	10.7	5.1	
732-E	8.3	4.4	
732-F	10.7	7.2	Dudley Shoals II Deposit, about 1½ miles west of Dudley Shoals
758	19.0	12.1	Dudley Shoals I Deposit, about 1½ miles west of Dudley Shoals, Caldwell County

\*Further discussion elsewhere in report.

## DESCRIPTION OF THE HEAVY MINERALS IN SILLIMANITE ORE FROM CLIFFSIDE-ELKIN BELT

Certain samples of the sinks were selected for microscopic study. The results of microscopic examinations of the washed and dried sinks are listed as follows:

648-C from Hollis, Rutherford County, had 11.6 percent sinks in acetylene tetrabromide. Microscopic examination revealed the presence of sillimanite, sericite alteration, chromite, rutile, zircon and zircon inclusions. The sillimanite is estimated to be 96 percent of the sinks with slight sericite alterations.



**648-D** road-cut samples from Cages Mountain, Caldwell County, had 14.6 percent sinks in acetylene tetrabromide. Microscopic examination revealed the presence of sillimanite, sericite alterations, biotite, pyrite, zircon and chromite. There were very extensive sericite alterations of the sillimanite (about 60 percent of the grain), which made up 90 percent of the sinks. Approximately five percent of the sinks were completely altered to sericite. Biotite and pyrite made up 7-8 percent of the sinks.

**648-E**, road-cut sample, from Fox's Orchard, Iredell County, had 13.8 percent sinks in acetylene tetrabromide. Microscopic examination revealed the presence of sillimanite, sericite alterations, garnet, epidote, chromite and zircon inclusions. The sillimanite is estimated to be 30 percent of the sinks, the garnet 50 percent, chromite 10 percent, epidote 5 percent. The sericite alterations were very slight.

**648-H**, surface float sample, from Cages Mountain, Caldwell County, had 13.4 percent sinks. Microscopic examination revealed the presence of sillimanite, sericite alterations, chromite, zircon inclusion, rutile and hematite. Ninety-six percent of the sinks were sillimanite and sericite alterations of sillimanite. The sericite alteration was very high with 3-5 percent of the sinks showing complete alteration.

**648-M**, surface float sample along Cedar Valley, Alexander County, had 12.0 percent sinks. Microscopic examination revealed the presence of sillimanite, sericite alterations, chromite, zircon, zircon inclusions and hematite. Ninety-four percent of the sinks were sillimanite or sericite alterations of the sillimanite. The sericite alterations were extensive (about 60 percent of grain) with 3-4 percent completely altered to sericite.

**668-B**, surface float sample from Cages Mountain, Caldwell County, had 14.8 percent sinks. Microscopic examination revealed the presence of sillimanite, tourmaline, garnet, rutile, and ilmenite. Sillimanite, about 50 percent of which is being altered to sericite, made up about 75-80 percent of the sinks. The extraneous material was mostly tourmaline (6-10 percent).

**668-C**, surface float from Cages Mountain, Caldwell County, had 13.6 percent sinks. Microscopic examination revealed the presence of sillimanite, rutile and ilmenite. Sillimanite, about 50 percent being altered by sericite, made up about 98-99 percent of the sinks. The extraneous material is rutile and ilmenite.

**668-D**, surface float sample from Cages Mountain, Caldwell County, had 12.2 percent sinks. Microscopic examination revealed the presence of sillimanite, ilmenite, rutile, and zircon. Sillimanite, about 50-55 percent being altered to sericite, made up about 93-95 percent of the sinks.

**668-F**, surface float sample from Cages Mountain, Caldwell County, had 14.2 percent sinks. Microscopic examination revealed the presence of sillimanite, ilmenite, a small amount of rutile and zircon, and a few zircon inclusions. Sillimanite, about 50 percent being altered to sericite, made up about 95-97 percent of the sinks.

**669-3**, surface float sample from Cages Mountain, Caldwell County, had 10.6 percent sinks. Microscopic examination revealed the presence of sillimanite, pyrite, and biotite. Sillimanite, with high sericite alteration, made up about 90-93 percent of the sinks and about 4-5 percent of the sinks was pyrite.

**669-5**, surface float sample from Cages Mountain, Caldwell County, had 15.4 percent sinks. Microscopic examination revealed the presence of sillimanite, ilmenite, pyrite, limonite, rutile, and zircon. Sillimanite, about 60 percent being altered to sericite, made up about 92-94 percent of the sinks, 2-3 percent was ilmenite, and 2-3 percent was pyrite and limonite.

**694**, high grade sample from road cut 4 miles south of Taylorsville, Alexander County, had 18.8 percent sinks. Microscopic examination revealed the presence of sillimanite, rutile, ilmenite, biotite, small amount of garnet, zircon and zircon inclusions, and a few tourmaline inclusions. Sillimanite, about 5-7 percent being altered to sericite, made up about 94-95 percent of the sinks. Most of the extraneous material was rutile (3 percent), and ilmenite.

**695**, chip road cut sample 4 miles south of Taylorsville on Highway 16, Alexander County, had 11.6 percent sinks. Microscopic examination revealed that sillimanite, about 2 percent being altered to sericite, made



up about 95 percent of the sinks. Most of the extraneous material was ilmenite and rutile. There was also some zircon and zircon inclusions and a few tourmaline inclusions.

**696-A**, road cut from Highway 16 on north side of Brush Mountain, Wilkes County, had 14.0 percent sinks. Microscopic examination revealed the presence of sillimanite, ilmenite, rutile, zircon and zircon inclusions, and a slight amount of magnetite, 90-92 percent of the sinks was sillimanite. Most of the extraneous material was ilmenite (4-5 percent) and rutile (3 percent).

**696-B**, sample from hill above road cut of 696-A on the north side of Brush Mountain of Highway 16, Wilkes County, had 13.4 percent sinks. Microscopic examination revealed the presence of sillimanite, ilmenite, rutile, garnet, zircon and zircon inclusions. Sillimanite, about 2 percent being altered to sericite, made up about 90-92 percent of the sinks. The extraneous material was about 5 percent ilmenite, 1-2 percent rutile, 1-2 percent zircon.

**707-A**, Dudley Shoals Deposit I, Caldwell County, had 24.0 percent sinks. Microscopic examination revealed the presence of sillimanite, hematite, specular hematite, staurolite, zircon and zircon inclusions, garnet, and tourmaline. Sillimanite, about 2 percent being altered to sericite, made up about 85-88 percent of the sinks and most of it was needle or lath shaped. 7-9 percent was hematite and specular hematite, 1-2 percent staurolite, 1 percent zircon and zircon inclusions.

**707-B**, Dudley Shoals Deposit I, Caldwell County, had 20.4 percent sinks. Microscopic examination revealed the presence of sillimanite, hematite, specular hematite, staurolite, small amount of garnet, zircon and zircon inclusions. Sillimanite, about 1-2 percent being altered to sericite, made up about 90 percent of the sinks. 6-8 percent of the extraneous material was hematite and specular hematite and about 2 percent was staurolite. The sillimanite was mostly needle or lath shaped.

**707-C**, Dudley Shoals Deposit III, Caldwell County, had 19.8 percent sinks. Microscopic examination revealed the presence of sillimanite, hematite, specular hematite, staurolite, garnet, zircon and zircon inclusions, 80-85 percent of the sinks was sillimanite with about 1 percent sericite alteration. Most of the extraneous material was hematite and specular hematite.

**707-D**, Dudley Shoals Deposit III, Caldwell County, had 35.2 percent sinks. Microscopic examination revealed the presence of sillimanite, hematite, specular hematite, staurolite, zircon and zircon inclusions, and a small amount of tourmaline. Sillimanite, about 1-2 percent being altered to sericite, made up about 90 percent of the sinks. 7-8 percent of the sinks was hematite and specular hematite, and 2-3 percent was staurolite.

**708-A**, road cut sample from Dudley Shoals Deposit II, Caldwell County, had 30.0 percent sinks. Microscopic examination revealed the presence of sillimanite, hematite, specular hematite, staurolite, zircon and zircon inclusions. Sillimanite, about 2 percent being altered by sericite, made up about 90-92 percent of the sinks. The extraneous material was mostly hematite and specular hematite, and about 3 percent staurolite.

**708-B**, sample from hill to east of road cut (708-A), Caldwell County, had 20.8 percent sinks. Microscopic examination revealed the presence of sillimanite, hematite, staurolite, small amount of garnet, zircon and zircon inclusions. Sillimanite, about 5-7 percent being altered to sericite, made up about 85 percent of the sinks, and was mostly needle-like. 9-10 percent was hematite, and 2-3 percent was staurolite.

**713-2**, float from ridge 5 miles N. E. of Hollis, Cleveland County, had 33.2 percent sinks. Microscopic examination revealed the presence of sillimanite, barite, rutile, ilmenite, hematite, zircon. Sillimanite made up about 85-90 percent of the sinks. About 6 percent of the sinks was barite. Very little sericite alteration was observed.

**713-4**, representative float from field 2 miles N. E. of Hollis, Cleveland County, had 12.8 percent sinks. Microscopic examination revealed the presence of sillimanite, barite, rutile, ilmenite, hematite, magnetite, and a few zircon inclusions. About 90 percent of the sinks was sillimanite with no alteration. 2-3 percent of the sinks was barite.



**713-8**, float from ridge 1 mile N. E. of Polkville, Cleveland County, had 24.8 percent sinks. Microscopic examination revealed the presence of sillimanite, ilmenite, staurolite, barite, hematite, garnet and zircon. About 90 percent of the sinks was sillimanite. There was very little sericite alteration.

**713-10**, float from field  $3\frac{1}{2}$  miles N. E. of Casar, Cleveland County, had 16 percent sinks. Microscopic examination revealed the presence of sillimanite, ilmenite, barite, staurolite, rutile, zircon, and a few zircon inclusions. About 95 percent of the sinks was sillimanite with practically no alteration to sericite. Most of the extraneous material was ilmenite.

**713-11**, sample from ridge and road cut 2.8 miles N. E. of Casar, Cleveland County, had 16.4 percent sinks. Microscopic examination revealed the presence of sillimanite, kyanite, ilmenite, hematite, barite, garnet, and staurolite. About 85 percent of the sinks was sillimanite. About 4-5 percent of the sinks was kyanite.

**713-13**, road cut sample and float from field  $3\frac{1}{2}$  miles north of Lawndale, Cleveland County, had 12 percent sinks. Microscopic examination revealed the presence of sillimanite, kyanite, ilmenite, staurolite, barite, and tourmaline. About 70 percent of the sinks was sillimanite, 20-25 percent of the sinks was kyanite.

#### ANALYSIS AND LOCATION OF SAMPLES FROM THE WARNE-SYLVA SILLIMANITE BELT

<i>Laboratory Number</i>	<i>Percent Sinks</i>	<i>Percent Sillimanite</i>	<i>Location</i>
604	6.2		Downing Creek Road, Clay County
605	3.6		North side Downing Creek, Clay County
606	12.6		Cherry Mountain area, Clay County
607	14.0		Half mile northeast of Downing Creek Church, Clay County
656*	32.9	26.3	Float sample from Grassy Ridge Mica Mine, Jackson County
673*	7.2	5.4	Road cut at Oak Forest Church, Clay County
674	7.6		Junction of Pecky Wood Branch and Sap Sucker Branch, Clay County
675	8.4		Downing Creek area, Clay County
687	8.0		Rainbow Spring-Aquone Road, Macon County
688-A*	16.2	5.7	} Rickman Creek, Macon County
688-B*	13.0	2.6	
689*	13.6	0.9	Near Leatherman, Macon County
690*	18.4	16.1	Near west fork of Potts Branch, Macon County
691-1*	21.0	18.9	} North of Saldeer Gap, Macon County
691-2*	14.0	12.0	
698-A*	10.8	10.0	} Bradley Creek near Oak Grove Church, Macon County
698-B*	11.8	10.8	
698-C	7.6		
698-D*	15.2	13.5	
698-E	9.8		
699*	19.8	8.4	Oak Grove area, Macon County
700*	13.8	9.7	Matlock Creek north of Owl Knob, Macon County
701*	14.4	10.1	Mouse Mountain, Macon County
702*	32.8	31.4	Rickman Creek area, Macon County
704*	20.6	5.8	Grassy Ridge Mica Mine, Jackson County
709	8.8		} Burningtown Creek road, Macon County
710*	11.2	9.5	
711*	20.1	19.5	Junction of Beasley and Huckleberry Creeks, Macon County
712	4.8		Southwest spur of Kings Mountain, Jackson County



<i>Laboratory Number</i>	<i>Percent Sinks</i>	<i>Percent Sillimanite</i>	<i>Location</i>
717*	13.6	6.4	Near Riverview Church on Tuckasegee River, Jackson County
736*	13.3	11.3	North end of Sylva, Jackson County
737*	18.3	17.4	Peewee Branch of Greens Creek, Jackson County
738*	14.0	13.7	Near Cowee Church, Macon County
739*	15.1	13.2	Southeast of Cowee Church, Macon County
740*	16.3	15.8	Between Saldeer Gap and Kelly Cove, Macon County
741*	6.7	6.4	Near Etna Post Office, Macon County
742*	21.3	19.6	One mile southeast of Dillsboro, Jackson County
743*	13.3	12.2	} About one mile southeast of Dillsboro, Jackson County
744	14.0	11.2	
745*	18.0	16.2	One-third Mile northwest of Riverview Church, Jackson County
746*	17.0	1.0	Shepherd Creek near Transmission line northwest of Leatherman, Macon County
751*	13.0	12.7	Half mile northwest of Sutton Branch, Greens Creek, Jackson County
752*	20.0		Near mouth of Sutton Branch of Greens Creek, Jackson County

\*Further discussion elsewhere in report.

## DESCRIPTION OF THE HEAVY MINERALS IN SILLIMANITE ORE FROM WARNE-SYLVA BELT

Certain samples of the sinks were selected for microscopic study. The results of microscopic examinations of the washed and dried sinks are listed as follows:

**656**, surface float sample near Grassy Ridge Mica Mine, Jackson County, had 32.9 percent sinks. Microscopic examination revealed sillimanite, garnet, chromite, zircon and zircon inclusions and biotite. Approximately 80 percent of the sinks were sillimanite, 10 percent were garnet and 5 percent were chromite.

**673**, road cut sample near Oak Forest Church, Clay County, had 7.2 percent sinks. Microscopic examination revealed the presence of sillimanite sericite alterations, chromite, ilmenite, garnet, rutile, staurolite, and zircon. The sinks were 75 percent sillimanite with high sericite alterations.

**688-A**, thirty foot channel sample from the east bank of the road on Rickman Branch, 1300 feet north of transmission line, 2.0 miles east, northeast of the Etna Post Office, Macon County, had 16.2 percent sinks. Microscopic examination revealed the presence of kyanite, sillimanite, ilmenite, small amount of specular hematite and zircon. About 30-35 percent was sillimanite, 60-70 percent kyanite, and 4-5 percent ilmenite.

**688-B**, location same as 688-A, had 13.0 percent sinks. Microscopic examination revealed the presence of kyanite, sillimanite, ilmenite, zircon, and a few zircon inclusions. About 75 percent was kyanite, 3-4 percent ilmenite, and about 20 percent sillimanite with high sericite alteration.

**689**, grab sample from west bank of the road 1600 feet NNW of Leatherman, about 3.6 miles ENE of Etna Post Office, Macon County, had 13.6 percent sinks. Microscopic examination revealed the presence of kyanite, sillimanite, rutile, ilmenite, garnet, zircon, and zircon inclusions, about 90 percent was kyanite, 6-7 percent sillimanite. The extraneous material was mostly rutile and ilmenite.

**690**, grab sample from west road cut, 150 feet west of West Fork of Potts Branch, 5100 feet WNW of Pleasant Hill Church, and 6600 feet ESE of Etna Post Office, Macon County, had 18.4 percent sinks. Microscopic examination revealed the presence of sillimanite, garnet, ilmenite, zircon, and very few pieces of kyanite and rutile. Sillimanite, about 20 percent being altered to sericite, made up 85-90 percent of the sinks. Garnet and ilmenite made up most of the extraneous material.



**691-1**, sample from ridge 1200 feet north of Saldeer Gap, 10,000 feet SSW of Etna Post Office, Macon County, had 21.0 percent sinks. Microscopic examination revealed the presence of sillimanite, hematite, and iron stained material, biotite, garnet, zircon and zircon inclusions, and very little kyanite. Sillimanite, about 70 percent being altered to sericite, made up about 90 percent of the sinks. Most of the extraneous material was hematite and iron stained material. There was less than 1 percent kyanite.

**691-2**, (same location as 691-1) had 14.0 percent sinks. Microscopic examination revealed the presence of sillimanite, hematite and iron stained material, garnet, zircon and few zircon inclusions, and very little kyanite. Sillimanite, about 70-75 percent being altered to sericite—1.2 percent complete alteration, made up about 85-87 percent of the sinks. Most of the extraneous material was hematite and iron stained material, 3 percent garnet.

**698-A**, road cut sample from Fred Bradley's place on Bradley Creek, 5,150 feet N.E. of Oak Grove Church, and 5,500 feet NNE of McCoy Bridge, Macon County, had 10.8 percent sinks. Microscopic examination revealed the presence of sillimanite, garnet, ilmenite, kyanite, zircon. Sillimanite, about 65-70 percent being altered to sericite, made up about 93 percent of the sinks. About one percent of the sinks was kyanite.

**698-B**, same locality as 698-A, had 11.8 percent sinks. Microscopic examination revealed the presence of sillimanite, garnet, ilmenite, hematite, zircon and kyanite. Sillimanite, about 70 percent being altered to sericite, made up about 92 percent of the sinks. About 1 percent of the sinks was kyanite.

**698-D**, same locality as 698-A, had 15.2 percent sinks. Microscopic examination revealed the presence of sillimanite, garnet, ilmenite, hematite, pyrite, zircon and zircon inclusions, small amount of staurolite, and kyanite. Sillimanite, about 60-65 percent being altered to sericite, made up about 88-90 percent of the sinks. About 1-2 percent of the sinks was kyanite.

**699**, road cut sample from Oak Grove Community, between Oak Grove Cemetery and U. S. Highway 64, Macon County, had 19.8 percent sinks. Microscopic examination revealed the presence of sillimanite, garnet, ilmenite, hematite, and kyanite. About 50 percent of the sinks was garnet and around 1-2 percent was kyanite. Sillimanite, about 80 percent being altered to sericite, made up about 40-45 percent of the sinks.

**700**, cut from east bank of creek above spring, on Matlock Creek at second creek crossing of county road, 5000 feet north of Owl Knob, 3.2 miles ENE of Etna Post Office, Macon County, had 13.8 percent sinks. Microscopic examination revealed the presence of sillimanite, kyanite, garnet, ilmenite, hematite, biotite, and zircon. Sillimanite, about 40 percent being altered to sericite, made up about 70 percent of the sinks. About 6 percent of the sinks was kyanite.

**701**, from Mouse Mountain 6,500 feet SSW of Grant Knob, and 9,100 feet WNW of Owl Knob, Macon County, had 14.4 percent sinks. Microscopic examination revealed the presence of sillimanite, hematite, garnet, rutile, and kyanite. Most of the extraneous material was iron oxide. Sillimanite, about 50 percent being altered to sericite, made up about 70 percent of the sinks. About 7 or 8 percent of the sinks was kyanite.

**702**, from Rickman Branch 4,800 feet N.W. of Owl Knob and 7,800 feet south of Grant Knob, Macon County, had 32.8 percent sinks. Microscopic examination revealed the presence of sillimanite, garnet, ilmenite, epidote and hematite. Sillimanite, about 30 percent being altered to sericite, made up about 96 percent of the sinks. (Sample not representative; sample taken for geologic control.)

**704**, chip sample from road cut near Grassy Ridge mica mine, Jackson County, had 20.6 percent sinks. 65-70 percent of the sinks was garnet, 25-30 percent sillimanite, and about 5 percent was rutile and ilmenite.

**710**, grab sample from Burningtown creek road on point of ridge going due west from Saldeer Gap, Macon County, had 11.2 percent sinks. Microscopic examination revealed the presence of sillimanite, hematite, ilmenite, rutile, barite, and zircon. Sillimanite, about 15-20 percent being altered to sericite, made up about 85 percent of the sinks.

**711**, grab sample from confluence of Beasley and Huckleberry Creeks, Macon County, had 20.1 percent sinks. Microscopic examination revealed the presence of sillimanite, kyanite, barite, garnet, ilmenite, and



zircon. Sillimanite, about 5 percent being altered to sericite, made up about 97 percent of the sinks. Kyanite made up less than 1 percent of the sinks.

**717**, sample taken 200 feet N.E. of Tuckasegee River, 1800 feet NNE of Riverview Church, about 1.8 miles S.W. of Sylva in Jackson County, had 13.6 percent sinks. Microscopic examination revealed the presence of sillimanite, garnet, kyanite, ilmenite, staurolite, and zircon. About 47 percent of the sinks was sillimanite.

**736**, channel sample from 30 ft. of section, 100 yards north of "Y" on U. S. 19 at intersection of first road to right after passing N. C. 107 going north, in Jackson County, had 13.3 percent sinks. Microscopic examination revealed the presence of sillimanite, iron oxide, ilmenite, garnet, kyanite, zircon, tourmaline, and staurolite. Very little alteration to sericite. About 85 percent sillimanite.

**737**, chip sample from 25 ft. of section 500 ft. north of mouth of Peewee Branch of Greens Creek, Jackson County, had 18.3 percent sinks. Microscopic examination revealed the presence of sillimanite, iron oxide, ilmenite, garnet, kyanite, and zircon. About 95 percent of the sinks was sillimanite and about 10 percent of the sillimanite is being altered to sericite.

**738**, sample from 60 ft. of section on U. S. 64, 1 mile south of West Mill, 700 ft. SSE of Cowee Church, Macon County, had 14.0 percent sinks. Microscopic examination revealed the presence of sillimanite, rutile, garnet, and very little ilmenite, iron oxide, zircon and zircon inclusions, biotite and kyanite. Most of the extraneous material was rutile. About 98 percent of the sinks was clear sillimanite.

**739**, sillimanite schist representing 60 ft. section, on U. S. 64 one mile south of West Mill, 1500 ft. SSE of Cowee Church, Macon County, had 15.1 percent sinks. Microscopic examination revealed the presence of sillimanite, ilmenite, epidote, kyanite, rutile, garnet, zircon and a few inclusions; 85-90 percent of the sinks was clear sillimanite.

**740**, sillimanite schist, 75 ft. of section, on point of ridge leading west from Saldeer Gap, 1500-1800 ft. south of the mouth of Kelly Cove Branch, Macon County, had 16.3 percent sinks. Microscopic examination revealed the presence of sillimanite, rutile, iron oxide, and a little ilmenite. Most of the extraneous material was rutile; about 97 percent (30 percent of which shows alteration to sericite) of the sinks was sillimanite.

**741**, sillimanite schist, 25 ft. of section, 200 ft. north of Etna Post Office, Macon County, had 6.7 percent sinks. Microscopic examination revealed the presence of sillimanite, garnet, iron oxide, kyanite and a small amount of ilmenite, zircon and rutile. About 96-97 percent of the sinks was sillimanite. Very high alteration to sericite (40-50 percent).

**742**, sillimanite gneiss, 40 ft. of section, 6000 ft. SSE of Dillsboro, 1,200 ft. north of Riverview Church, Jackson County, had 21.3 percent sinks. Microscopic examination revealed the presence of sillimanite, garnet, biotite, small amount of ilmenite and iron oxide. Most of the extraneous material was garnet. About 92 percent (5-10 percent alteration to sericite) of the sinks was sillimanite.

**743**, sillimanite gneiss 5,800 ft. SSE of Dillsboro, 1,500 ft. north of Riverview Church, Jackson County, had 13.3 percent sinks. Microscopic examination revealed the presence of sillimanite, garnet, kyanite, and a very small amount of staurolite, ilmenite, tourmaline, iron oxide, zircon, rutile and biotite. About 92-93 percent (about 10 percent being altered to sericite) of the sinks was sillimanite.

**744**, sillimanite gneiss 5,800 ft. SSE of Dillsboro, 1,500 ft. NNW of Riverview Church, Jackson County, had 14.0 percent sinks. Microscopic examination revealed the presence of sillimanite, garnet, epidote and a small amount of ilmenite, zircon, biotite, and kyanite. Most of the extraneous material was garnet. About 80 percent of the sinks was sillimanite.

**745**, sillimanite gneiss, 30 ft. of section, 5,600 ft. SSE of Dillsboro, 1,800 ft. NNW of Riverview Church, Jackson County, had 18.0 percent sinks. Microscopic examination revealed the presence of sillimanite, garnet and a small amount of ilmenite, staurolite, biotite and zircon. Most of the extraneous material was garnet. About 90 percent of the sinks was sillimanite.



746, kyanite-sillimanite gneiss from Shepherd Creek, 2.5 miles NE of West Mill, under transmission line 1,300 ft. NNW of Leatherman, Macon County, had 17.0 percent sinks. Microscopic examination revealed the presence of kyanite, sillimanite, garnet, epidote, rutile and a very few zircon inclusions. About 5-7 percent of the sinks was sillimanite. About 90 percent of the sinks was kyanite. (Some alteration to sericite.)

751, 2,200 ft. NW of mouth of Sutton Branch of Greens Creek, Jackson County, had 13.0 percent sinks. Microscopic examination revealed the presence of sillimanite, garnet, ilmenite, biotite, zircon. About 98 percent of the sinks was sillimanite. Very little alteration to sericite.

752, chip channel sample of sillimanite schist, 60 ft. of section, 350 ft. NW of mouth of Sutton Branch of Greens Creek, Jackson County, had 20.0 percent sinks. Microscopic examination revealed the presence of sillimanite, garnet, ilmenite, and a small amount of staurolite, zircon and iron oxide.

## BENEFICIATION

### INTRODUCTION

The following pages prepared by Mason K. Banks present a general summary of laboratory beneficiation work as applied to ores from some of the deposits discussed in the geological section of this bulletin. There has been no coordinated laboratory program in connection with the field survey so far as detailed beneficiation test work is concerned. The results shown were obtained by sporadic test work, either on ores of particular field interest, or whenever a request was made for small amounts of concentrates by ceramic or refractory interests for research purposes, thus they do not represent results of a finished, polished process, but are shown merely to indicate what is possible with some of the deposits located by the field party.

By use of flotation (with oleic acid, sodium pyrophosphate, and sodium meta silicate) at fine sizes (at least minus 100 mesh), all ores tested will yield high grade sillimanite concentrates, unless the sillimanite was sericitized. Sericitization causes low recovery and low-alumina concentrates. In reducing the  $\text{Fe}_2\text{O}_3$  content of the concentrates to below 1.0 percent, it was often necessary to pass the concentrates through a Franz ferro-filter. In samples where weathering had caused red iron oxide staining of the sillimanite particles, leaching with zinc hydrosulfite and sulfuric acid was effective in improving the color and also in reducing the iron content of the concentrates.

### PROCEDURE

**Cages Mountain Deposit**—Laboratory sample No. 648-H from Cages Mountain deposit, Caldwell County, contained 12.2 percent sillimanite by heavy liquid and microscopic assay, most of which was partially altered to sericite. A small amount of graphite also was present, along with biotite, quartz, and trace amounts of iron-titanium minerals. Since the minerals were locked down to fine sizes, flotation was the method used with feed ground to minus 200 mesh.

Concentration of this ore was complicated by sericitization of the sillimanite which prevented the successful preparation of a high-alumina concentrate, it being virtually impossible to selectively float unaltered sillimanite particles from altered particles. Test No. 2 shows that the alumina content of the concentrates was improved by reducing the recovery drastically. This was accomplished by reducing the amount of collector, thereby concentrating only the most readily floatable particles. The use of sericite depressants was unsuccessful.

The preparation of low-iron concentrates was not particularly difficult. Control of pH was vital in depressing iron minerals. A pH of  $7.0 \pm 0.3$  in the rougher and first cleaner was necessary for effective depression of iron minerals.

Results of two tests, both performed on feed ground to minus 200 mesh in a pebble mill are shown below. Test 1 shows high recovery with low alumina due to sericite. Test 2 shows low recovery, with correspondingly higher alumina.



## TEST 1

	Oleic Acid	pH	Sodium Pyro-phosphate	Emuosol	Sodium Metasilicate	Sulfuric Acid
Pebble Mill.....			1.0			
Graphite Float.....				0.2		
Sillimanite Rougher Float.....	1.9	6.9				
Sillimanite Cleaner Float.....	0.2	7.0	0.5		0.3	0.20
Sillimanite Cleaner Float.....	0.1	6.9	0.5			0.08
Sillimanite Cleaner Float.....	0.2	4.4				0.10
Results:.....	% Wt.	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	TiO <sub>2</sub>	
Sillimanite concentrates.....	14.2	56.4	0.75	39.0	0.3	

## TEST 2

	Oleic Acid	Sodium Pyro-phosphate	Emulsol	Sodium Metasilicate	Sulfuric Acid
Pebble Mill.....		1.0			
Graphite Float.....			0.2		
Sillimanite Rougher Float.....	1.55				
Sillimanite Cleaner Float.....	.02	1.0		0.2	
Sillimanite Cleaner Float.....	.01				
Sillimanite Cleaner Float.....	.02				0.2
Results:.....	% Wt.	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	TiO <sub>2</sub>
Sillimanite concentrates.....	7.0	59.4	0.9	38.5	0.1

Concentrates similar to those shown in Test 1 are being studied by the Ceramic Engineering Department, Clemson College, South Carolina.

**Fox's Orchard Deposit**—The laboratory samples from Fox's Orchard deposit, Caldwell County, were designated Laboratory numbers 614, 615, 616 and 662. The ore contained an average of 12 percent of sericitized sillimanite. In addition to the usual quartz and biotite, the ore contained graphite, pyrite, and titanite. The more weathered portions contained much clay and some alum.

The same problem encountered in samples from the Cages Mountain deposit caused considerable difficulty in concentrating this ore. Sericitization of the sillimanite resulted in low alumina content of the flotation concentrates. The presence of pyrite and alum caused rather high consumption of sodium metasilicate in obtaining the desired pH for flotation.

Emulsol XI was found to be a good collector for the graphite in the ore. Following graphite removal, it was necessary to remove the pyrite with xanthate. After pyrite flotation, the sillimanite was floated with an emulsion of oleic acid and Emulsol XI, using sodium pyrophosphate as an iron-mineral depressant. The emulsion of oleic acid and Emulsol XI showed an improvement over straight oleic acid. It had stronger collection properties and seemed to give improved iron-mineral rejection. Best results on Sample No. 615 (24 percent sillimanite) using the above-outlined procedure are as follows: Recovery—85.5%; Al<sub>2</sub>O<sub>3</sub>—55.9%; Fe<sub>2</sub>O<sub>3</sub>—2.0%; SiO<sub>2</sub>—39.8%; TiO<sub>2</sub>—0.3%. The tests were performed on feed ground to minus 200 mesh. The Fe<sub>2</sub>O<sub>3</sub> content of the concentrate could probably be lowered by passing the flotation concentrate through a ferro-filter.

**Smith Cliff Deposit**—Several samples of ore from the Smith Cliff deposit near Morganton, Burke County, were tested. Sample No. 44 consisted of nodules picked up on the surface. Samples Nos. 46 and 307 were nodular schist. Sample No. 47 was residual weathered schist. Sample No. 45 was the "needle" schist type. Sample No. 538 was the sericitized schist type.



A minus  $\frac{1}{2}$  inch plus 20 mesh sample of crushed hand-picked nodules from Sample No. 44 which analyzed  $\text{Al}_2\text{O}_3$  60.6%;  $\text{Fe}_2\text{O}_3$  0.7%  $\text{SiO}_2$  37.0%, was submitted to the U. S. Bureau of Mines, Electrotechnical Laboratory, Norris, Tennessee, for refractory evaluation. Although this sample was not prepared by commercially reproducible methods, it is probable that a similar product could be prepared by using heavy media procedure, followed by magnetic separation to reduce the iron content. At the time this work was done equipment was not at hand to attempt such a procedure.

Sample No. 307, after grinding to minus 200 mesh and floating with oleic acid, sodium metasilicate, and sodium pyrophosphate, yielded the following products:

	% Wt.	% Sillimanite	Sillimanite Distribution
Sillimanite Concentrates.....	18.9	94.0	73.5
Sillimanite middlings.....	6.3	45.0	11.5
Sillimanite trailings.....	50.5	5.0	10.3
Sillimanite slimes.....	24.3	5.0	4.7
Total.....	100.0	24.3	100.0

The above concentrate had the following analysis:  $\text{Al}_2\text{O}_3$  58.7%;  $\text{Fe}_2\text{O}_3$  3.0%;  $\text{SiO}_2$  36.4%.

Sample No. 538 contained 11 percent partially sericitized sillimanite and graphite, quartz, muscovite, biotite and garnet. Using the oleic acid, sodium silicate, sodium pyrophosphate float after an emulsol graphite float on 35 mesh, 65 mesh, and 100 mesh feed, the following results were obtained:

Grind	Recovery	$\text{Al}_2\text{O}_3$	$\text{Fe}_2\text{O}_3$	$\text{SiO}_2$	$\text{TiO}_2$
35 mesh	61	48.1	6.8	38.0	1.0
65	62	57.9	3.3	36.2	0.7
100	59	58.3	3.4	35.6	0.7

From the above data, it was concluded that the ore should be ground to minus 100 mesh in order to liberate the sillimanite. Accordingly, a minus 100 mesh flotation concentrate was made, passed through a ferro-filter, then leached with zinc hydrosulfite and sulfuric acid. Results were as follows:

	Recovery	$\text{Al}_2\text{O}_3$	$\text{Fe}_2\text{O}_3$	$\text{SiO}_2$	$\text{TiO}_2$
Flotation.....	61%		4.4		
Ferro-Filter.....	53		2.6		
Leach.....	53	59.7	1.4	35.8	0.5

The problem of high  $\text{Fe}_2\text{O}_3$  due to oxide stains and locked grains at fine sizes prevented preparation of coarse concentrates from this sample. Minus 100 mesh concentrates, which would run 5-6 percent weight of ore processed with approximately one percent  $\text{Fe}_2\text{O}_3$ , could be prepared by flotation, ferro-filtering, and leaching.

**Dudley Shoals Deposits**—A number of samples tested from the Dudley Shoals deposits are classified as follows: (1) "schist type," containing 12-20 percent sillimanite disseminated in fine sizes in quartz-biotite schist (Laboratory Nos. 694 and 730). (2) "soil type," containing 3-6 percent minus 16 mesh grains of clean residual sillimanite and 3-12 percent plus 16 mesh iron-stained nodules of sillimanite (Laboratory Nos. 692-B to F, 731-A and B, 758 and 838). (3) "nodule type," consisting of nodules of sillimanite varying in size from  $\frac{1}{4}$  inch up to four feet across which occur scattered through the soils of the Dudley Shoals deposits (Laboratory Nos. 692-A and 757).

Type 1, "schist type," presents the problem, as do the other schist types, of flotation at minus 200 mesh. The sillimanite from these deposits, however, is not sericitized to any appreciable extent. Results obtained from flotation of Laboratory No. 694, representing this type, were as follows: Recovery 76%;  $\text{Al}_2\text{O}_3$  61.5%;  $\text{Fe}_2\text{O}_3$  0.7%;  $\text{SiO}_2$  37.3%;  $\text{TiO}_2$  0.3%. The concentrate has both high alumina and low iron.



Type 2, "the soil type," offers possibility of production of both minus 16 mesh flotation concentrates and plus 16 mesh refractory material, although production of the refractory-sized material presents a very difficult problem. Laboratory numbers 758 and 838 were used in these tests.

The minus 16 mesh was prepared as follows: The crude sample was screened on a 16 mesh vibrating screen. The minus 16 mesh sands were scrubbed with caustic and deslimed at 325 mesh. The deslimed sands were dried and screened on a 60 mesh Hummer screen. The minus 16 mesh plus 60 mesh portion was discarded as it contained less than 1 percent sillimanite.

The minus 60 mesh deslimed sands, containing roughly 14 percent sillimanite, was floated with oleic acid, sodium metasilicate, and sodium pyrophosphate. The rougher float was cleaned twice with oleic acid and sulfuric acid. The cleaned froth product was then de-oiled and ferro-filtered three times. Metallurgical results from this procedure are shown below:

Results:	% Wt.	Silli- manite Distri- bution	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	TiO <sub>2</sub>	Ign.
Sillimanite concentrate.....	13.4	96%	61.6	0.71	36.5	0.47	0.45
Rougher tails.....	79.8	4					
Cleaner tails.....	3.4						
Re-cleaner tails.....	1.5						
Magnetic Fraction.....	1.9						

Thirty pounds of the above concentrate were submitted to the Department of Engineering Research, North Carolina State College, Raleigh, North Carolina for study.

The plus 16 mesh fraction of the "soil type" samples contained about 22 percent sillimanite in the form of rather badly iron-stained nodules. A possible method of beneficiation would be to pass the material through a heavy-media separating unit and then pass the sinks over a magnetic separator. The laboratory did not have an adequate magnetic separator for such a procedure, but a simulation was performed as follows: A representative sample was placed in acetylene tetrabromide (specific gravity 2.96), and the sillimanite removed as sinks and gangue minerals removed as floats. The sinks were then passed over by a hand magnet to remove the most magnetic (high iron) portion. Results are shown below:

	% Wt.	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	TiO <sub>2</sub>
Floats.....	45.0				
Magnetic sinks.....	25.6				
Non-magnetic sinks.....	29.4	53.4	9.1	36.6	0.3
Total.....	100.0				

The hand magnet was not strong enough to remove all of the iron-bearing particles. Although the simulation outlined above failed to produce low-iron refractory sillimanite, the procedure should not be abandoned until it is tried using a suitable magnetic separator, which might lower the iron to the range of refractory specifications.

Type 3, "the large nodule type," as represented by Samples No. 692-A, analyzed 59.3 percent Al<sub>2</sub>O<sub>3</sub> and 2.7 percent Fe<sub>2</sub>O<sub>3</sub> without beneficiation. No attempt has been made to reduce the iron at refractory size range, but after grinding to minus 100 mesh, the material was passed through a ferro-filter and leached with zinc hydrosulfite and sulfuric acid. The product from this treatment analyzed as follows: Al<sub>2</sub>O<sub>3</sub>—60.2%; Fe<sub>2</sub>O<sub>3</sub>—1.1%; SiO<sub>2</sub>—38.3%; TiO<sub>2</sub>—0.2%.

Large nodules in Sample No. 757 were crushed to minus  $\frac{3}{4}$  inch and the minus  $\frac{3}{4}$  inch plus  $\frac{1}{4}$  inch fraction contained: Al<sub>2</sub>O<sub>3</sub>—58.2%; Fe<sub>2</sub>O<sub>3</sub>—2.5%; SiO<sub>2</sub>—38.3%; TiO<sub>2</sub>—0.6%. Hand-picked pieces from this product analyzed Al<sub>2</sub>O<sub>3</sub>—60.8%; Fe<sub>2</sub>O<sub>3</sub>—0.49%; SiO<sub>2</sub>—38.6%; TiO<sub>2</sub>—0.12%.

**Grassy Ridge Deposit**—Sample No. 704 was taken from a sillimanite schist outcropping on Grassy Ridge, Balsam Gap, Jackson County. This is the only sample from the western sillimanite belt on which any flotation tests were performed. The ore contained 5 percent sillimanite.



Using feed ground to minus 200 mesh, with the conventional oleic acid-sodium metasilicate-sodium pyrophosphate flotation procedure, a recovery of 80 percent of the sillimanite was effected, having the following chemical analysis:  $\text{Al}_2\text{O}_3$  62.6%;  $\text{Fe}_2\text{O}_3$  2.0%;  $\text{SiO}_2$  34.8%;  $\text{TiO}_2$  0.3%.

This concentrate has a very high alumina content, although the iron is somewhat high. The alumina content is an illustration of what can be done if the sillimanite is not sericitized. All of the sillimanite in this sample was clean and fresh with no sericite alteration.

## CONCLUSION

Given a schist containing 15-20 percent sillimanite which is not appreciably sericitized, a minus 100 mesh concentrate containing 60 percent or more  $\text{Al}_2\text{O}_3$  and 1.0 percent or less  $\text{Fe}_2\text{O}_3$  may be produced by froth flotation. It is sometimes necessary to follow flotation with leaching and ferro-filtering. Whether or not there is a market for a high grade sillimanite concentrate in the minus 100 mesh size range is not known.

There is a market for material in the minus  $\frac{3}{4}$  inch plus 8 mesh size range for refractory use. Unfortunately, only the Dudley Shoals and Smith Cliff deposits contain sillimanite in large enough crystal sizes to make refractory grog, and both of these contain a high percentage of iron, which occurs as oxide stain and as locked iron-bearing minerals. The only successful method of reducing the iron was achieved by first grinding the nodules to minus 100 mesh, the reduction in size thus destroying their usefulness as refractory material. A method which might be practicable for concentration of refractory material from nodular sillimanite would be the use of heavy-media, followed by magnetic separation of the sinks to reduce the iron content. This method was simulated and results shown under the Dudley Shoals section. The iron content was still far too high, but lack of a suitable magnetic separator was partly responsible.

Summarizing, a minus 100 mesh flotation concentrate of excellent grade can be produced from almost any unsericitized sillimanite schist. However, production of a refractory material still remains an unsolved problem due both to lack of suitable prospected deposits and, consequently, lack of opportunity to develop a suitable beneficiation method.

## PROSPECTING, MINING, AND RESERVES

In the search for sillimanite certain factors should be considered. In reconnaissance surveys unusual characteristics of soils are important. As a rule, soil underlain by sillimanite-bearing rocks contain fragments of only partially weathered rock along with the soil and is characterized by a "pebbly" appearance. In the Cliffside-Elkin belt the sheared character of the sillimanite-bearing rock imparts a "fragmental" appearance.

Anyone interested in prospecting for sillimanite should not rely too greatly upon the abundance of sillimanite float as an indication of a large underlying deposit.<sup>14</sup> The sillimanite ore has a much greater resistance to physical and chemical weathering than does the country rock, thus frequently a series of narrow zones with thick intervening barren zones may, upon weathering, leave numerous fragments of sillimanite in the soil. This leaves the erroneous impression that the entire area is underlain by sillimanite-bearing rock.

Once a sillimanite occurrence has been located, perhaps the best method of preliminary prospecting is by pits and trenches which would serve to outline the deposit. These openings should, where possible, be of a cross-cutting nature and extend to sufficient depth to expose rock in place, but not necessarily fresh, unweathered rock. Channel samples should be obtained from the occurrence and the sillimanite content and characteristics of the sillimanite concentrate studied. If, at this stage, the deposit still shows promise, core drilling should be undertaken.

Before the start of active mining, large samples of ore should be processed through the pilot plant stage in order to determine their milling characteristics, since various sillimanite ores react differently to any one beneficiation process.



The North Carolina sillimanite deposits generally occur in low, elongated ridges, thus open cut quarrying or mining can be used. In the Cliffside-Elkin belt, although there is considerable variation in the amount of overburden, firm rock generally will be encountered at depths between 15 and 30 feet. At some of the deposits the overburden material contains sufficient sillimanite to justify its processing to recover the mineral. Depth to fresh unweathered rock in this belt is not known. In the Warne-Sylva belt there is no apparent topographic expression related to the sillimanite rock, however, since the sillimanite occurs in mountainous terrain, open cut mining methods can be used. Overburden thickness ranges from a foot or two up to as much as 75 feet, depending upon the distance from streams.

Because of the variable concentration of the sillimanite ore, more or less selective mining should be practiced in any mining operation. Granite and pegmatite intrusions in the deposits which exceed a few feet in thickness can be removed from the ore before milling, however, because of the *lit par lit* nature of the pegmatite intrusions and the sillimanite-bearing rock a considerable amount of barren rock will have to be milled.

Although no accurate estimates as to the reserves are available in either of the two belts, the depth to which sillimanite extends being unknown; certain general statements about reserves can be made. In the Cliffside-Elkin belt, listed in order of size, the principal deposits are: Smith-Cliff deposit, Cages Mountain deposit, and the Dudley Shoals deposits. This estimate of reserve is based on the size of the deposit and not on the sillimanite content.

In the Warne-Sylva belt, as has been pointed out previously, zones of sillimanite-bearing rock up to several hundred feet thick occur, but, due to discontinuous exposures, lengths of the various occurrences are unknown. It is believed, however, that those deposits described in detail in the chapter on "Descriptions of Deposits" contain sufficient reserves to permit the operation of a plant of moderate size.

## POSSIBILITIES FOR DEVELOPMENT

The annual consumption of the high alumina silicate minerals which include kyanite, andalusite, and dumortierite, can be estimated only roughly, as many of the producers of these minerals are also consumers, thus true production figures are not available. It is believed that the preparation of a high quality concentrate would permit marketing of more than 20,000 tons of sillimanite per annum. Domestic high aluminous materials suited for high temperature use are distributed quite widely, except for some of the more promising materials such as massive topaz from Chesterfield, South Carolina,<sup>1</sup> and massive kyanite similar to Indian kyanite from Georgia<sup>2</sup> which occur in limited quantity. The use of andalusite and dumortierite from the western states has been restricted to specialized production, since the location and character of the deposits are such that large production is impractical. Crystalline bladed kyanite, disseminated throughout metamorphic schists and gneisses, is abundant in the southeastern states. Its use in refractories requiring coarse grog has been limited however, because of its decrepitation characteristics during calcination.

No domestic deposits of sillimanite have been worked on a commercial scale. The known deposits of domestic sillimanite, like the kyanite in the southeastern states, occurs as disseminated crystals in metamorphosed rock, thus before use it will require beneficiation. In comparison with kyanite, sillimanite does not require pre-calcination before use, and the grain size of the sillimanite particles is limited to that size which can be obtained during extraction of the mineral.

Similar conditions are involved in the mining of sillimanite and kyanite, and mining costs are comparable. The only two active producers of kyanite in the southeast at present, located in Virginia and South Carolina, recover kyanite which occurs disseminated in quartzite. Kyanite content of those ores now in production range between 20 and 35 percent, which is probably higher than any of the deposits discussed in this report. Local sillimanite contents, however, range up to 35 percent.

The only successful method developed to date to recover the sillimanite content of sillimanite-bearing rock which occurs in North Carolina has been flotation. Alteration of the sillimanite to sericite has caused considerable variation in the reaction of sillimanite ores to flotation. Also the sericite, which is extremely difficult to separate from the sillimanite, lowers the refractiveness and is evident in the chemical composition



of the concentrate as the aluminum content is lowered with a corresponding increase in the potassium content.

In order to exploit the sillimanite deposits in North Carolina, it will be necessary to produce a concentrate at approximately the same or slightly higher cost as compared to kyanite and, if the cost is higher, with corresponding improvements in thermal characteristics. It is thought that the ore should contain in excess of 10 percent sillimanite with a minimum of sericite alteration. A deposit, in order to be commercial, should have a tonnage reserve of at least 1,000,000 tons, and should be situated near rail transportation and a dependable water supply.

Because of the disseminated nature of the sillimanite ore, a large amount of sillimanite in fine sizes will result from any operation. It will be necessary to develop a market, probably in the ceramic porcelain industry, to utilize this finer sillimanite fraction. A certain amount of iron oxide is present in all of the concentrates prepared to date. In order to produce a high quality concentrate, this iron contamination should be kept to a minimum. In order to obtain this condition, it may be necessary to resort to magnetic separation and/or acid leaching of the concentrate.



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